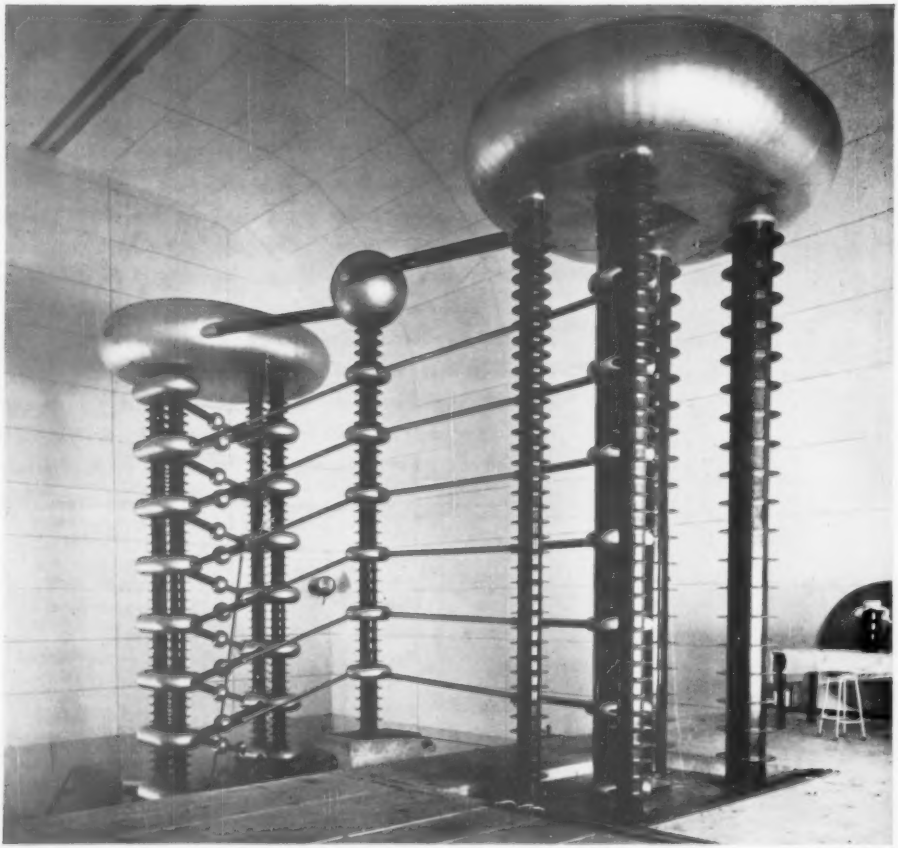
NUCLEONICS



1.2-Mev accelerator at Australian National University, Canberra, is first and largest such machine in Australia. Output from 7-stage Cockcroft-Walton generator in background is fed through RC smoothing filter in center to accelerator tube in foreground

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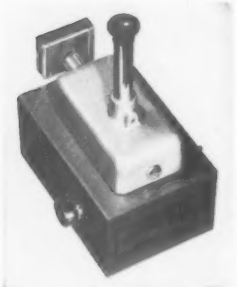
Victoreen Pocket Dosimeters ... For Every Purpose

THE MODEL 287 CHARGER-READER is used with the Model 362 chamber, and operates from 110 volts A.C.



THE MODEL 392 is a battery operated unit for charging and reading the Model 506 and 507 chambers.

A dosimeter is an instrument which measures the total accumulated quantity (dosage) of X or gamma radiation. The reading is in roentgens regardless of exposure time. Pocket dosimeters, sometimes called pocket chambers, are either direct reading or indirect reading. Direct reading pocket chambers have a built-in optical system and electrometer, which permits the wearer to periodically observe the dosage which has accumulated since the chamber was last charged, thus enabling him to retreat from a hazardous area when the dosage approaches the average daily tolerance. Indirect reading dosimeters require a Minometer (charger-reader) to observe the reading. This reading is usually checked at the end of the working day by a competent technician.

MODEL	TYPE	FULL SCALE SENSITIVITY	CONDITIONS
362	Indirect	0.2 r	At or below daily Tolerance Rate
541	Direct	0.2 r	At or above daily Tolerance Rate
547	Direct	5. r	Emergency
548	Direct	50. r	Trained personnel—Emergency
534	Direct	5. and 50. r	Civil defense, etc.
506	Indirect	100. r	Untrained personnel—Emergency
507	Indirect	200. r	Untrained personnel—Emergency

Write for Bulletin 3012

The Victoreen Instrument Co.

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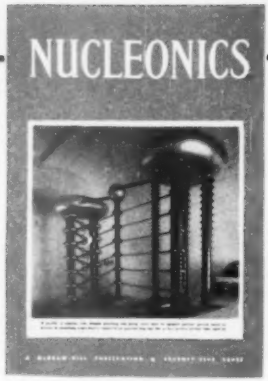

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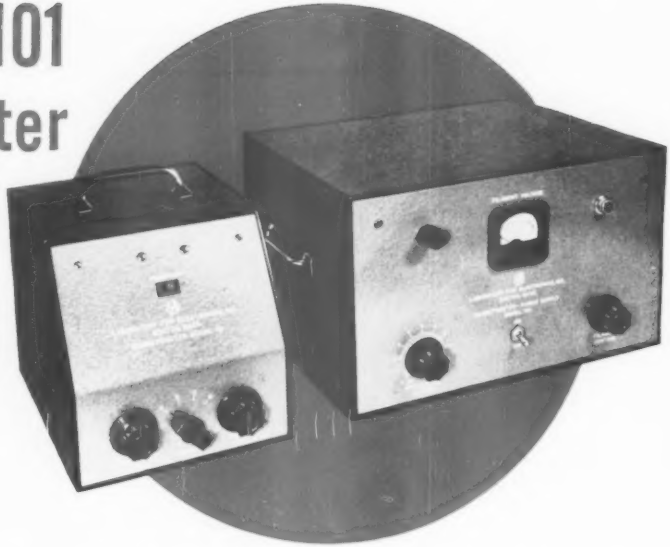
New Model 101 Magnetometer



accurately measures magnetic field strength using the principle of nuclear resonance

The Magnetometer translates the problem of the measurement of magnetic field strength to the much more accurately solved one of the measurement of a radio frequency. An oscillatory magnetic field is provided by means of a coil surrounding a sample which permits measurement of proton resonance and the nuclear resonance of lithium (Li^7). The coil is part of an oscillator which is so designed that its level of oscillation drops with an increase in circuit losses, such as may be introduced by nuclear resonance in the sample material. Means are provided to make this resonance easily viewed on an oscilloscope.

The nuclear resonance effect is very small and requires a magnetic field homogeneity of at least one part in 500 for proton resonance and one part in 5000 for lithium over the dimension of the sample, to be readily detected. Due to its very high available accuracy, limited only by the accuracy of the frequency measuring equipment, the Magnetometer has many applications in the fields of research, instruction and control.

SPECIFICATIONS

Range of Magnetic Field Strength
Proton resonance: 300-8000 gauss
Lithium resonance: 7000-25000 gauss

Frequency to Field Ratio
Protons: 4257.76 ± 0.10 ∿/ gauss
Lithium (Li^7): 1654.61 ± 0.10 ∿/ gauss

Modulation Sweep Width Range
1.6 to 16 gauss

Power Requirements
115 volts, 60 cycles, 30 watts

Frequency Range
Probe 1: 1.18 to 2.84 mc Probe 2: 2.61 to 6.25 mc
Probe 3: 5.6 to 13.5 mc Probe 4: 13 to 34 mc

Area of Sample Material
Probe 1: 0.5 sq. cm. Probe 2: 0.3 sq. cm.
Probes 3 and 4: 0.32 sq. cm.

Size of Probe and Cable
Cable: 18" long Probe: ¾" Diam. ⅝" W.

Size of Units
Oscillator Cabinet: 7 9/32" W x 9 7/16" D x 7 5/8" H
Power Supply Cabinet: 13½" W x 10⅜" D x 8⅜" H

Price—$725 F. O. B. Boston, Mass.

For complete information see your LFE engineering representative or write direct.

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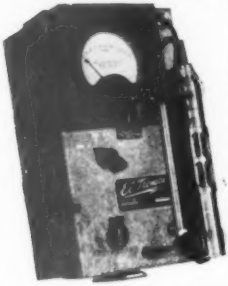
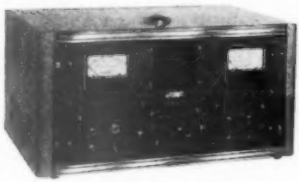
Model PR-3 SURVEY INSTRUMENT



Specifically designed for portable field and laboratory use, this Radiation survey instrument offers 3 individual scales of .2, 2.0, and 20 MR/HR. Scales are in distinctive colors and automatically change with range switch, preventing visual reading error. Easily accessible battery compartment permits changes of inexpensive "A" and "B" batteries. Probe has 30 in. cable. This instrument is rugged and lightweight—weighs 8½ lbs.

Model RM 4B COUNTING RATE METER

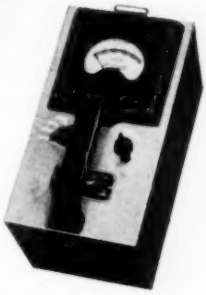


A complete counting rate meter of laboratory accuracy for use with scintillation, Geiger or Flow Gas Counters has input sensitivity of ¼ volt. Gives fast indication of radiation intensity. Meter is calibrated in both counts per second and counts per minute. Ranges of 5, 50, 500, and 5000 counts per second and 300, 3000, 30,000, and 300,000 counts per minute are provided. A loudspeaker permits aural monitering. Regulated high voltage supply applies constant potential to the counter tube. Terminals provided for recording instruments and pre-amplifer. Write for Bulletin.

LS 64 SS LABORATORY SCINTILLATION SCALER

This extremely accurate Binary laboratory scintillation scaler makes precise measurements of radiation intensities. Employs reliable Higinbotham scaling circuit with a built-in impulse register. Scaling ratios at 4, 8, 32, or 64. Sixteen predetermined shut-off points. Terminations provided for oscilloscope, synchronous clock, and preset timer.

PR 50 IONIZATION TYPE SURVEY METER



A wide range ionization chamber type gamma survey meter for rugged field or portable laboratory use. Five full ranges of 5, 50, 500, 5000, and 50,000 MR/HR are read directly from a large 4 inch meter. Meter scale colors change with range to eliminate visual error. Off, battery check, and zero adjust positions are provided. This meter meets all requirements for Civil Defense. Constructed to military specifications. Has a calibration accuracy of ±15%. Write for Bulletin.

Model SDH—SCINTILLATION COUNTER

A scintillation counter head for making extremely sensitive measurement of radiation intensities containing a 5819 photo-multiplier tube surrounded by a mu-metal shield. A NaiThallium activated crystal is mounted in a highly polished lucite holder to assure accuracy and a cylindrical lead shield entirely surrounds the crystal housing. Furnished complete with 5819 tube, crystal and cable. Write for Bulletin.

Model LSC—SHIELDED SAMPLE TEST CHANGER

Accurate readings through lowered background count make this shielded sample test changer unusually reliable. Two inches of lead in front of and behind sample drawer cause sample to be completely enclosed. GM tube readily accessible from top. The sample drawer is provided with removable shelves so that fast sample changes are possible. Write for Bulletin.

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MODEL AH-1 GAMMOMETER

a radiation measuring instrument requiring

NO HIGH VOLTAGE POWER SUPPLY

Utilizing the newly introduced, exclusive OHMART Cell (in which radioactive energy is converted directly into electrical energy) as the radioactive element, the OHMART Model AH-1 Gammometer requires NO high voltage power supply. The result is an instrument unparalleled in its field for long-time precision, dependability, and simplicity of operation. No longer is it necessary to hire special staffs of electronics experts to operate and maintain complicated equipment—thanks to the instrument's amazing simplicity. And this simplicity, plus the advantage of direct readings, means that time is saved, errors are reduced in day to day use—hence further savings for you.

The Model AH-1 Gammometer is designed for the analytical measurement of microcurie quantities of gamma activity. Applications may be made for precise measurement of radioisotopes required in following chemical processes, in isotope evaluation, and in dosage preparation. The unit will take liquid samples up to 15 milliliters; and solid samples up to ⅞" outside diameter by 2" in length. Samples are placed in a well in the center of the cell, resulting in increased precision, since the quantities of activity are much larger than when slides are prepared, and geometry errors are minimized. The ranges are 1, 10, 100 and 1000 microcuries; a master calibration control, permitting calibration for the material being measured, makes it possible to obtain results directly in terms of microcuries of activity without any calculations. The price of the Model AH-1 Gammometer is $580.00 F.O.B. Cincinnati, less tax; for convenient portability, a blue leatherette, felt-lined carrying case is available for an additional $31.00.

Also available are the models AH and A Gammometers, with ranges from as low as .1 microcurie to 10,000 microcuries full scale calibrated in terms of radium (standard), Iodine-131, or Cobalt-60. For measurement of ambient field intensity, the units are available calibrated in milliroentgen per hour from .1 to 10,000 mr/hr. full scale.

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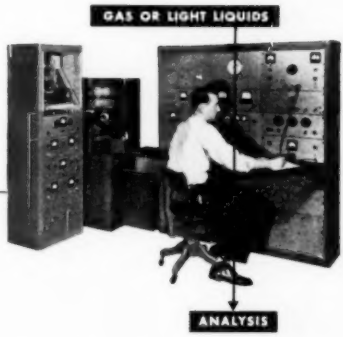

A complete, accurate analysis of a complex chemical mixture can now be made by one operator in minutes instead of hours or even days with the Model 21-103 Consolidated Mass Spectrometer.

The mixture being analyzed may be composed of organic or inorganic compounds. Virtually any gas or liquid sample may be handled so long as the individual components in the mixture exert a minimum vapor pressure of 250 microns at room temperature. Trace impurities constituting as little as 0.001 mole per cent of the mixture can be determined.

Speed and accuracy of analysis, together with versatility, make this the ideal instrument for the chemical industry. For further information on the Model 21-103, write for Bulletin CEC-1800B.

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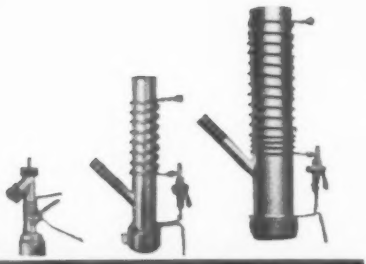

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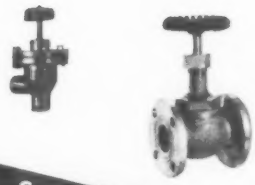

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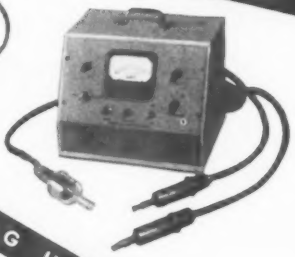

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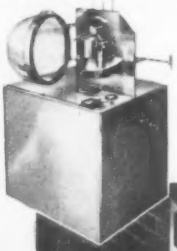

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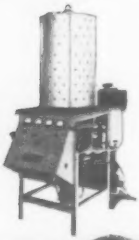
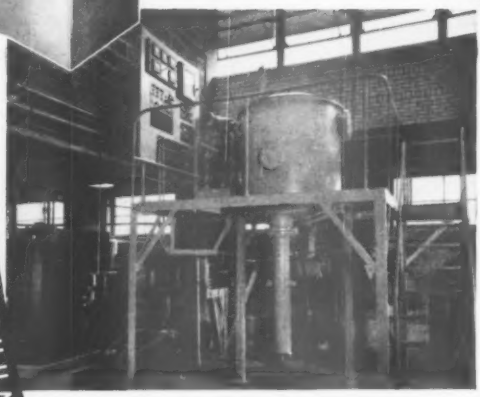
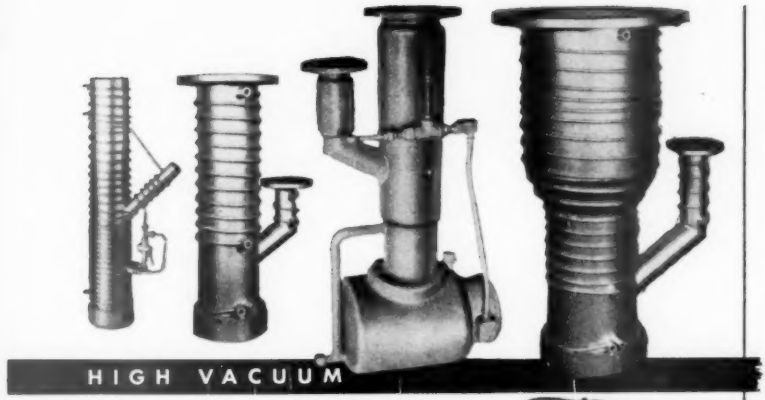
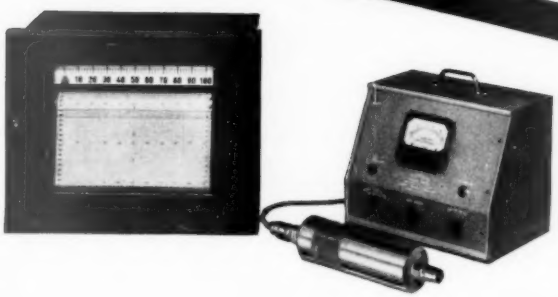
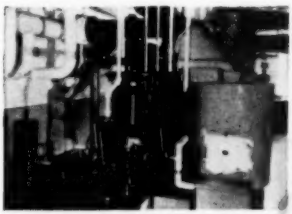




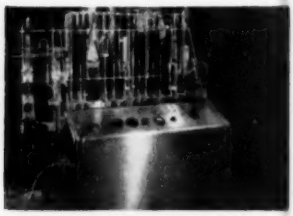




Special Equipment and Plant Installations



V25D Rotary Condenser. A typical processing unit in a large, high vacuum plant which we designed and built.



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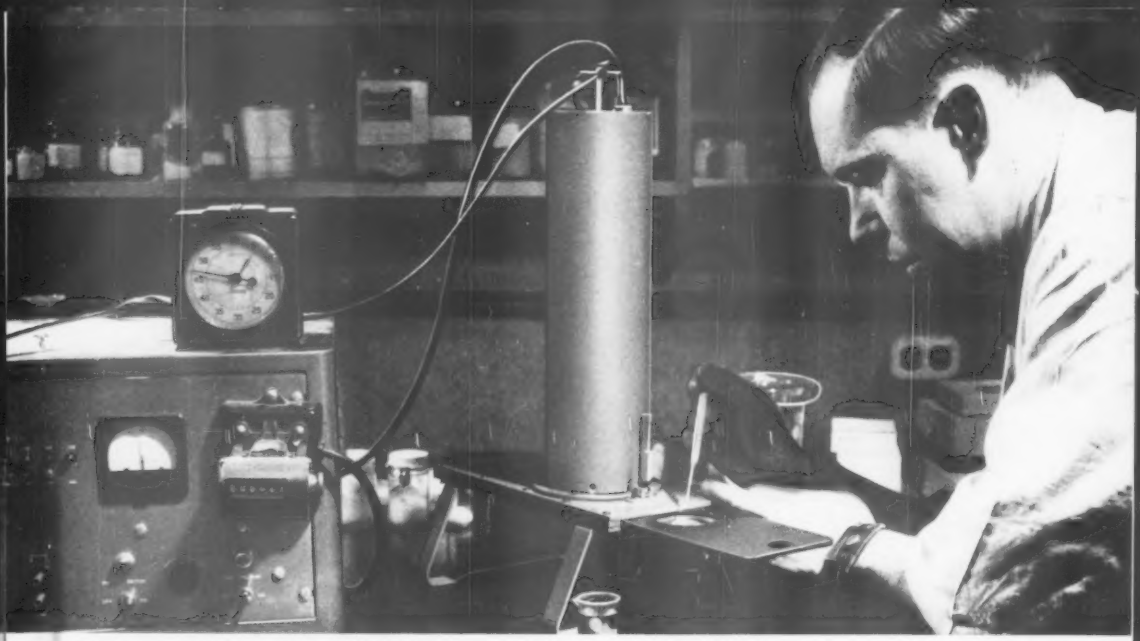
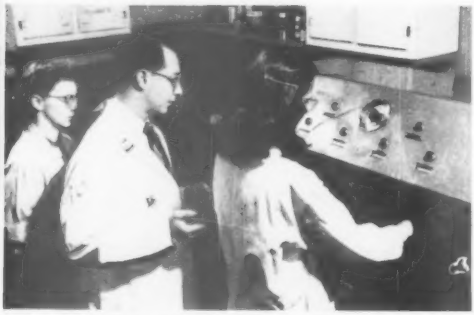


1 **G-E UNIVERSAL SCINTILLATION COUNTER** detects alpha, beta, gamma, and thermal neutron radiation on smears from contaminated surfaces. Phosphors can be rapidly interchanged. Any standard scaler can be used for counting.

New Instruments Detect Radiation Hazard



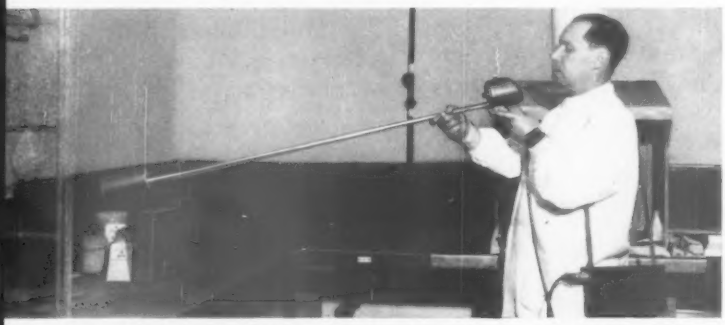
2 **G-E ALPHA HAND COUNTER,** a fast means of obtaining routine check on workers' hands for alpha contamination.

To help safeguard personnel encountering radioactive materials, the G-E Scintillation Counter (above) is also obtainable in portable form. Standard connector at rear of probe allows connecting cable of any length up to 50 feet. It is well adapted for contamination surveys of particle accelerators and nuclear reactors. A modified probe can be used for water monitoring.

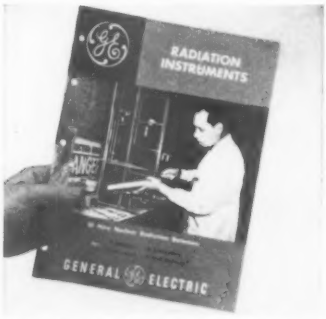
The long-probe (below) is supplied in either four- or six-foot lengths. Range from 0.3 to 3000 roentgens per hour. Power is obtained from batteries in lightweight carrying case, permitting complete portability.

Write for catalog GEA-5735 to: General Electric Co., Sect. 687-93, Schenectady 5, N. Y.

GENERAL ELECTRIC



3 **G-E LONG PROBE GAMMA SURVEY METER** monitors areas of high-level gamma radiation. Helps locate beam of particle accelerators with minimum risk to user.



Write for new 8-page catalog of General Electric radiation detection instruments.

NUCLEONICS

APRIL, 1952

Power vs Isotopes

Although we are living in an age when readers of *Astounding Science Fiction* claim that most new scientific discoveries or ideas are "old hat," our imagination is jolted nearly every day by new advances in the atomic energy field. For instance, an announcement from Paris last month told about the proposed use of the French reactor in an attempt to solve an "Arsenic and Old Lace" murder case. Sample hair from the heads of each of eleven supposed victims of arsenic poisoning are to be irradiated in the pile in the hopes that the amounts of radio-arsenic formed will provide the solution.

This is only one of numerous dramatic uses of nuclear reactors or their byproducts—radio-isotopes—which pop up constantly. It raises the question of what the long-range effect of atomic energy will be. Will nuclear power or radioisotopes—which are what we mean when we talk about atomic energy—have the greater impact on us?

The power aspect has been debated hotly month after month. But right now it is thought of in very limited terms. Insufficient engineering has been done to permit any valid estimates on whether nuclear power can compete economically with conventional systems. Studies being carried out now are predicated on the fact that part of the cost of a nuclear power plant would have to be paid for by the Government in the form of a guaranteed price for plutonium produced.

Thus, we will probably pass through two stages, the first where nuclear power is not competitive and the second where it is. In the first, nuclear power plants will spring up where their special characteristics make them particularly suitable. The most likely situation is where the weightless nuclear fuel will permit power plants in places where the distance from conventional fuel markets makes the cost of such fuel prohibitive. Such places might be countries or parts of countries which are undeveloped or have untapped natural resources awaiting the availability of fuel. Another likely application, which is being diligently pursued by the military, is in nuclear-propelled ships and aircraft.

When nuclear power becomes competitive, either because of technological advances or because of increased costs or disappearance of other power sources, it will obviously begin to encroach on areas served by present central power stations.

The most valuable long-term effect of nuclear power may be the possibility for further development of the resources of this country and the rest of the world. There would then be the continued existence of a billion-dollar industry, including mining, refining, separating and chemical processing plants.

The value of radioisotopes will be felt in an entirely different way. Benefits from nuclear power will probably be easily measurable in dollars and cents. Not so with radioisotopes.

They are already useful in every branch of science and in many phases of industry. They are doing things that can't be done by other methods. They are helping to push back the frontiers of basic knowledge. They are aiding in improving and controlling industrial processes.

All their applications may not be as spectacular as that in the French murder case, but in addition to saving lives or money, radioisotopes are sure to add to our knowledge and technology in ways undreamed of today.

If the impact of nuclear power is like that of a giant who can't conceal his presence, the merit of a radioisotope is like that of a pygmy who works unobtrusively, quietly—and surely.

—*J.D.L.*

What's Wrong with Our Atomic Energy Program

An oustanding scientist who for 2½ years held the important post of Director of Research of the AEC tells why we do not yet have nuclear power plants. In a forthright analysis of the AEC organization, Dr. Pitzer is strongly critical of the extensive use of advisory committees

KENNETH S. PITZER
Dean, College of Chemistry
University of California
Berkeley, California

IT IS NOT CLEAR today in what commercial use the special characteristics of atomic power will be most important. It may be central station power in remote locations or possibly super-speed long-range airliners. The military needs will fully occupy the power reactor development program for some time to come, but these developments will be largely applicable to other types eventually. However, we should press hard for economy in these military reactors, not only to save money now, but also to have a more favorable point of departure for commercial uses when that time arrives. Furthermore there must be a bold point of view, a willingness to try new types of reactors even though one cannot be absolutely sure in advance that they will be successful.

I would like to offer some general comments on policy questions and on the effectiveness of our atomic energy effort. I would like to discuss the areas closer to our major development objectives: weapons and power. It is easy to offer sweeping generalizations in favor of or against something. But such comments are seldom the whole story and certainly would not be in this case. The AEC is reasonably efficient by general governmental standards, but I believe we have a right to expect something special in this vital area. Consequently, I hope I can offer some critical comments without having these interpreted as a sweeping condemnation.

Our atomic energy team has a large roster of good players, but its performance could be improved by some changes in the coaching staff. Also some of the rules under which it plays seem to slow up the game unnecessarily.

The good sound players are the men in the atomic energy plants and laboratories. Some star performers left in 1945 and 1946 at the end of the war; but after a reorganization period new leaders emerged, gained stature and experience, and are now giving comparable performance to the old stars.

However, in many cases the basic rules of procedure are not conducive to the best results. There is something wrong when David E. Lilienthal, the advocate—even the symbol—of public power says, "The time for the first industrial applications of atomic knowledge is overdue—let's end government monopoly and give American competitive industry a chance." I do not agree with many of the details of Mr. Lilienthal's arguments, but I believe he is correct in pointing the finger at monopoly.

In spite of Congressional investigations, monopoly tends to be a comfortable position. If unnecessary time is taken to reach a decision, there is no competitor here at home to move into the field ahead of you. If there are unnecessary men employed on a job, it's just part of the cost—there is no danger of losing money on the job. This lack of real incentive to reduce costs, tends always to leave the cost floating around at some level, not disgracefully high, but not necessarily near rock bottom. How can we ever find the true cost of atomic power if the actual costs are inflated?

Of course part of the difficulty is the intrinsic military use of all the principal products of atomic energy at this time. But there are contracting methods which give the contractor an extra

profit if he improves efficiency which could be used more widely than they are. The Congress should encourage the Commission to suggest means by which its degree of monopoly could be reduced and should then cooperate in their implementation.

However, it must be admitted that it will take some time to get away from the AEC monopoly. Can we not make more rapid progress toward both military objectives and useful atomic power in the meantime? I believe we could.

During the war the first reactors and the bombs were actually produced within about three years. At that time, if there was a major disagreement as to the best route to follow in a development, both routes were followed. In the more recent period the reverse has been the usual case—when disagreement arose neither route was followed until an exhaustive series of preliminary studies was completed. This might well delay the project a year or more. Such delays are actually expensive, because all sorts of costs continue during the indecision.

After the successful operation of the Hanford reactors, the additional task to build a power reactor was certainly no more difficult than had been the original wartime assignment. Yet it was over six years later when the reactor at Idaho first produced 100 kw last December.

The slowness did not arise from a lack of designs for power reactors which reputable scientists and engineers were willing to build and test. It came rather from an unwillingness of the Commission to proceed with any one of these designs until all of the advisers agreed that this was the best design.

The situation might be likened to an automobile equipped with separate brake levers for each passenger. At every road junction the driver not only had to discuss his preference of route with his riders, but he had to wait until all were convinced, because any one could stop the car. Considering that the power reactor territory is not clearly mapped, it is not surprising that more time was spent stationary than moving. We need either to remove some of the extra brakes or to

SUMMARY OF CRITICISMS

By

KENNETH S. PITZER

1 "In many cases, the basic rules of procedure are not conducive to the best results."

2 "Monopoly tends to be a comfortable position."

3 "How can we ever find the true cost of atomic power if the actual costs are inflated?"

4 "There are contracting methods which give the contractor an extra profit if he improves efficiency which could be used more widely than they are."

5 "Can we not make more rapid progress toward both military objectives and useful atomic power?"

6 "Slowness [in building a power reactor] . . . came . . . from an unwillingness . . . to proceed with any one of these designs until all of the advisers agreed that this was the best design."

7 "I presume [the advisory committees] of noted experts were intended to shield the Commission itself from criticism if some project should fail."

8 "We have gone to silly extremes [in safety measures for reactors]."

9 "This decision [to postpone building of certain key reactors until an ultrasafe proving ground could be found] delayed the reactor development program at least a year."

10 "Far too many [of the advisory committees] are actually impeding the work in spite of good intentions."

11 "The proper role of the General Advisory Committee has now changed and there needs to be a corresponding change in membership."

AEC COMMITTEE SYSTEM

The 20 committees listed below provide a framework within which the AEC operates. The first three are statutory (required by the McMahon Act). There are 14 so-called advisory bodies. Some of these are permanent, others are temporary. The number of these has fluctuated.

Statutory Committees

Joint Congressional Committee on Atomic Energy

Made up of nine members of the Senate and nine of House. This "watchdog" group keeps tabs on the broad aspects of the program. Major policy decisions or legislative changes go through this group.

Military Liaison Committee

Consists of representatives from each of the military branches. Guides the AEC on its weapons program.

General Advisory Committee

Advises AEC on scientific and technical matters relating to materials, production, and research and development. Consists of 7 scientists, two men from industry and 1 engineer. Averages 6 meetings a year.

Senior Responsible Reviewers

Reviews the major phases of the AEC program and is the principal adviser to the AEC on declassification matters.

Advisory Bodies to the AEC

Advisory Committee on Biology and Medicine

Reviews AEC programs in medical and biological research and health, and recommends to the Commission general policies in these fields. Has held 29 meetings since September, 1947.

Advisory Committee on Chemistry

Advises on policy concerning the program of supporting basic unclassified chemistry research in universities, and the relationship of this program to the AEC's own chemistry research program.

Community Operations Panel

Studies problems of introducing private ownership of real property and self-government in AEC-owned communities.

Advisory Board of Contract Appeals

Hears contract appeals arising under "disputes articles" of AEC contracts and sub-contracts.

Advisory Committee on Isotope Distribution

Aids in establishing new policies on distributing radioactive materials and reviews existing policies. Also reviews all initial applications for use of radioisotopes in human beings and all other requests for their use in research, education and industry.

Patent Advisory Panel

Makes informal reports and recommendations to the Commission on various questions of policy and procedure relating to patents and inventions covered by the McMahon Act.

Advisory Committee on Personnel Management

Meets once a month and continuously reviews AEC's personnel management practices.

Personnel Security Review Board

Reviews specific personnel security cases. Also, in its monthly meetings, advises on broader considerations regarding personnel security, such as criteria for determining eligibility for security clearance and personnel security procedures.

Committee on Raw Materials

Advises on questions of exploration, development and procurement.

Industrial Committee on Reactor Location Problems

This newly-formed committee will assist and advise the Commission in determining the criteria to be used in the location of atomic energy plants with regard to populated areas and in evaluating the adequacy and necessity for the isolation of such plants.

Reactor Safeguard Committee

This committee reviews safety studies made by the contractors on proposed reactors for completeness and accuracy and may make recommendations for modifications or further study.

Stack Gas Problem Working Group

Advises on development of methods and equipment for keeping the atmosphere at and near AEC's installations free of toxic or radioactive contamination.

Technical Information Panel

Representatives of major AEC research contractors advise on all aspects of AEC's Technical Information Service.

Ad Hoc Committee on Technological Information for Industry

Advises on ways to improve the dissemination of technological information to industry.

Patent Compensation Board

Holds hearings on applications for compensation or royalty fees based on patent claims made under the McMahon Act.

Atomic Energy Labor Relations Panel

This is a permanent panel appointed by the President to take jurisdiction and mediate labor-management disputes which threaten to interfere with the essential operations of the AEC.

shift riders to men who will reply to the driver "take the road that you think best and let's move ahead."

In my analogy there is one necessary passenger with a brake lever—this is the Commission itself. However, the other passengers are there by the Commission's invitation. They are a multitude of part-time advisory groups and boards. Although the motive is not stated, I presume these boards of noted experts were intended to shield the Commission itself from criticism if some project should fail. But let me give you one example of how such a board tends to operate.

Extremes in Safety

A reactor is potentially explosive—like a steam boiler or a gas tank—therefore safety considerations are appropriate. The devices, analogous to safety valves on the boiler, should be installed to make reactors as safe as possible and this must be very safe! No one questions the need of all reasonable safety features, but we have actually gone to silly extremes.

Both the Argonne and Oak Ridge Laboratories are situated on large tracts of land where isolated test sites are available. The reactor designers in the laboratories included all types of safety features in their plans. Nevertheless, it would be entirely reasonable to ask an independent committee to check these designs to see if any errors were made.

But instead of that, the committee was asked to report whether there was any hazard at all in the operation of the reactors on the sites proposed. Of course, you can always hypothesize that all safety devices fail and that some extreme form of sabotage is committed. Then one can assume the most unfavorable possibility in every subsequent part of the catastrophe.

On that basis a gasoline tank truck has more explosive potential than a blockbuster TNT bomb and should never be allowed in a city at all. Yet with all the accidents involving gasoline trucks, this maximum explosion has never occurred. It would be absurd to forbid gasoline trucks to enter city streets—more moderate safety restrictions are sufficient.

No reactor has ever exploded, and we are continuously learning how to make even safer types. Still, when a committee is asked, effectively, to take responsibility for reactor safety without any balanced authority over mode of operation or other factors, I do not blame them for pointing out these ridiculously remote risks. Yet the report, once formally issued, led the cautious Commission to hold up the reactor projects until the vast Idaho Proving Ground could be procured.

The Proving Ground is probably a wise investment, because it makes it possible to test the most high-powered and sensitive reactors without the caution that nearby populations would necessitate. But the safer and smaller models could have been built without any significant risk on the original Argonne and Oak Ridge sites with great savings in both time and money.

I believe this decision delayed the reactor development program at least a year. The mistake was the failure to trust the laboratory directors and reactor project engineers—the very men who knew the most about the problems and the men who were really staking their reputations and lives on the safety of their designs.

Multitude of Advisers

The last AEC report shows sixteen of these part time advisory committees appointed by the Commission in addition to the several statutory committees. Some of these groups are helping to get the job done but I am afraid far too many of them are actually impeding the work in spite of good intentions. These should either be abolished or shifted to report to a subordinate official who can steer their efforts in a constructive direction. There are now too many cooks tasting the broth before it is served; there are too many sources of a high level negative decision which, once rendered, is then nearly impossible to overcome.

The AEC has able and responsible men in charge of most of its projects and laboratories. The Commission should show more confidence in them. Of course, if any individuals do not merit this confidence, they can be replaced. The Commission should make the goal and the budget clear in each case and then support the group that is doing the job instead of calling upon part time advisers and consultants to double and triple check each step.

In summary the rule changes should bring in more incentive to efficiency and cost reduction and should give greater authority to project managers who are getting jobs done.

This leads to my suggestion that some changes in the coaching staff would be desirable. I refer particularly to some of the most influential members of the statutory General Advisory Committee who have served continuously since the establishment of the Commission. These are able men for whom I have a very high personal regard. No doubt they served an important role during the period when new leaders were being developed in the laboratories. However I believe the proper role of the General Advisory Committee has now changed and there needs to be a corresponding change in membership. We now need men who will specialize in pointing out new fields to explore rather than in double checking decisions in projects already under way.

Enthusiasm Needed

Also, I am sorry to say that some of these Committee members of long standing seem to have remarkably little enthusiasm for the primary goals of the atomic energy program. Their recommendations on military projects are, of course, secret, and I am not at liberty to discuss them. Concerning useful power, some have spoken publicly. Dr. James B. Conant has stated that he has little hope for useful atomic power and has predicted that in the 1960's the effort in that direction will be abandoned. Certain other members of the committee have expressed similar opinions. Certainly more constructive advice should be obtainable from men with faith and enthusiasm in the job to be done.

There are men of comparable stature who are on record as believing great new developments in atomic energy are possible. These include Dr. Harold C. Urey, Nobel Laureate, Dr. Farrington Daniels, president-elect of the American Chemical Society, and Dr. Charles Thomas, ex-president of ACS and president of Monsanto Chemical Co.

When Mr. Lilienthal had lost his enthusiasm for the atomic energy job he stepped aside. I am sure we will get more vigorous leadership, both on the Commission and on the advisory committees, from men who have enthusiasm for the general program than from those who do not.

* * *

This article is based on an address before the Southern California Section of the American Chemical Society, Los Angeles, California, March 7, 1952.

Survey Methods for Slow Neutrons

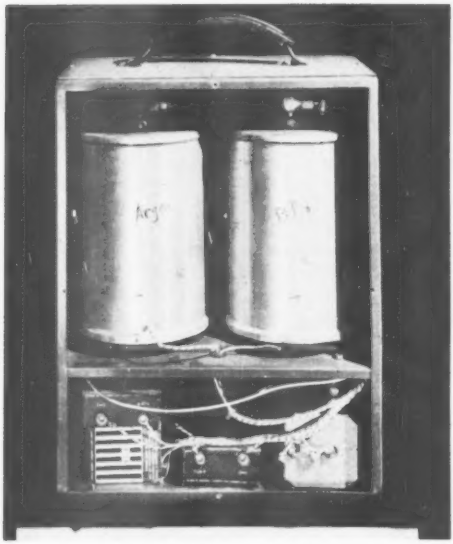


FIG. 1. Rear view of balanced-chamber type slow-neutron survey instrument. Rear wall is removed. Microammeter and controls are on front

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The neutron hazard around accelerators and reactors can best be evaluated by considering separately the different energy regions. Reviewed here are three methods for measuring thermal and near-thermal neutrons

To ONE WHOSE responsibility it is to make evaluations of the degree of hazard existing in the radiation field of a nuclear accelerator or a nuclear reactor, the valid estimate of the contribution of neutrons to such a field is of considerable importance. The degree of difficulty of such a measurement depends strongly upon the information desired—whether (1) simply the presence of "slow" and "fast" neutrons in significant numbers is in question, or (2) a measure of flux densities within known energy intervals is required, or (3) a direct estimate of the specific rate of energy absorption due to neutron-produced effects in a given medium is desired.

The importance of securing trustworthy estimates of the neutron field can be appreciated by recalling that the biological damage due to a given amount of ionization produced in biological tissue by effects due to neutrons is estimated to be several times the damage due to a similar amount of ionization produced by X-rays or gamma rays. This "relative biological effectiveness" must be evaluated by carefully controlled animal experiments. Its value appears to range from about 2.5 for slow neutrons to about 10 for fast and high-energy neutrons. Of course, the value obtained may also be a function of the particular biological variable under observation, and from some experiments a value as high as 20 for fast neutrons may be indicated (*1*).

It is generally understood that the reason for the greater biological damage associated with neutron-produced ionization compared to that from X-rays or gamma rays lies in the matter of specific ionization. Along the tracks of recoil particles and secondary charged nuclear particles from neutron interactions, the ionization per unit path length is about 100 times that along the tracks of the Compton and photoelectrons produced by X-rays and gamma rays. So even if the total energy loss per unit mass of medium were the same, these differences in local concentration of the effects would produce different degrees of damage to the organism. These same differences in specific ionization provide a basis for the selective detection of fast-neutron effects in the presence of a gamma-ray background.

Furthermore, the development in recent years of accelerators that deliver nuclear particles with energies extending into the hundreds of Mev

has introduced a few special considerations. The high-energy neutrons from such machines almost completely dominate the shielding problem, being much more penetrating than any gamma radiation (*2*). Also, such neutrons are capable of producing nuclear "stars" in which a large fraction of the neutron energy may be delivered into a small volume of space in the form of high-energy nuclear fragments. The quantitative, selective detection of neutrons of these energies requires instruments quite distinct from those employed in the fast region.

If one is concerned simply with an evaluation of the specific energy absorption by soft biological tissue from a radiation field of any type, one may have recourse to the "tissue-equivalent" chamber technique so carefully developed by Gray, and by Failla and Rossi (*3*). If prior knowledge is available concerning the relative biological effectiveness of the radiation field in question, and if it is assumed that the energy absorption in soft tissue (usually measured in the "roentgen equivalent physical" unit) multiplied by this relative biological effectiveness will give the desired hazard index, then the use of these chambers (or of approximations thereto) is to be recommended.

The subject matter of the present article, however, assumes a desire to evaluate the various components of a radiation field, and in particular the specific neutron contributions. Methods will be described for estimating flux densities or energy absorption rates for thermal and near-thermal neutrons. One of these uses the portable instrument shown in Fig. 1. Methods for fast (0.3–15 Mev) and high-energy (above 20 Mev) neutrons will be described in an article in the May, 1952, NUCLEONICS.

Whenever feasible, one desires to employ alternative methods in a given evaluation so as to provide either assurance, or criticism, of its validity. The discussion here is not exhaustive, but will involve some of the leading ideas currently in use.

From the standpoint of biological effects, slow neutrons are those for which capture by nitrogen nuclei and by protons are the important phenomena in the development of absorbable energy within a biological medium (*4*). This means that slow neutrons will here include both the thermal and capture-resonance energy regions.

At these low energies, the typical energy transfers by elastic collisions are neither sufficiently large to produce many ionizing particles nor to rupture many chemical bonds, and the outstanding processes by which damage may occur will be such exothermic capture events as those mentioned above. The capture by protons yields 2.2-Mev gamma radiation; the nitrogen capture reaction is $N^{14}(n,p)C^{14}$, with 0.62 Mev available to the proton.

To measure selectively the slow-neutron flux density, advantage is taken of certain unique reactions which can be measured easily, even in the presence of effects due to gamma radiation and fast neutrons which may also contribute to the field. Notable among such reactions is the capture event $B^{10}(n,\alpha)Li^7$.

BF_3 Counters

The rate of neutron capture events in a volume, V, of BF_3 gas possessing N atoms of B^{10} per cm^3 is

$$R = NV\int n(v)\,v\,\sigma(v)\,dv$$

where $n(v)$ is the density of neutrons per unit velocity interval at velocity v, and $\sigma(v)$ is the B^{10} capture cross section at velocity v.

Since $\sigma(v)$ is nearly proportional to $1/v$ in the slow neutron region, it may be written as

$$\sigma(v) = \sigma_0 v_0/v$$

where σ_0 is the thermal capture cross section for B^{10} (3,960 barns) and v_0 is the mean thermal-neutron velocity (2.2×10^5 cm/sec). Then

$$R = NV\sigma_0 v_0 \int n(v)dv = NV\sigma_0 v_0 \rho$$

where ρ is the numerical density of slow neutrons.

Thus a BF_3 counter is, strictly speaking, sensitive to the integrated *numerical density* of neutrons within the velocity range in which the $1/v$ dependence is valid. If the velocity spectrum, $n(v)$, is known sufficiently well to define an average velocity $\bar{v}$, then the flux density is given by

$$\rho_{\bar{v}} = \frac{R}{NV\sigma_0} \times \frac{\bar{v}}{v_0} \qquad (1)$$

In practice, the velocity spectrum for a neutron atmosphere which has penetrated the typical shielding around a neutron source (cyclotron, etc.) is peaked enough at thermal energies to allow approximation of $\bar{v}$ by v_0 for the accuracy needed in slow-neutron hazard evaluation. In any case, the degree to which the BF_3 is responding to neutrons above about 0.5 ev may be ascertained by enclosing the chamber in a sheet of Cd (20 or 30 mils thick), which will absorb nearly all the neutrons below this energy.

Measurement of R, the rate of B^{10} capture events, may be accomplished by pulse counting, the volume V being the sensitive volume of a proportional counter or of an ionization chamber. If the dimensions of the volume are large compared to the range of the alpha particle and of the recoil Li^7 nucleus, the wall effects are small, and the sensitive volume is easily estimated (*5*).

The foregoing has assumed that slow-neutron absorption by the counter walls is negligible. Whether or not this is true depends upon the material and thickness of the walls. These should be so chosen as to make this effect small, and calculable from known slow-neutron capture cross sections. In particular, glass walls containing boron (such as Pyrex glass) are to be avoided. Important aspects

Neutron Classifications

There are three classes of neutrons, based on their energies . . .

1. Slow neutrons have thermal and near-thermal energies below, 0.3 Mev.
2. Fast neutrons have energies above the capture-resonance region, 0.3 Mev, and up to about 15 Mev.
3. High-energy neutrons have energies greater than typical nuclear binding energies, 15 or 20 Mev.

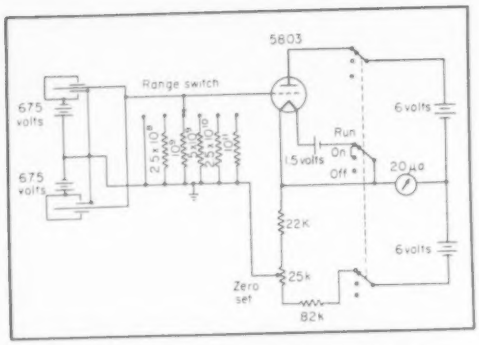

FIG. 2. Electrometer circuit for balanced-chamber instrument

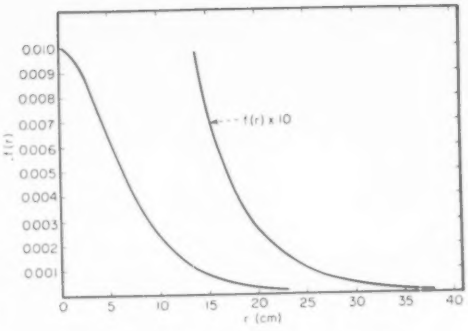

FIG. 3. Plot of $(f)r$ from data of Rush (10)

of preparing BF_3 proportional counters and pulse chambers have been discussed by Fowler and Tunnicliffe (6).

BF_3 Ionization-Current Method

Because of the difficulty of rendering pulse amplifiers and recorders easily portable, it is often convenient to make use of electrometer circuits to measure R by providing a reading of the ionization current collected out of a volume V. Since each capture event releases 2.34 Mev as kinetic energy of the alpha and Li^7 particles, and since this energy is lost by ionization and excitation with a quota of about 30 ev per ion pair, the ionization-current contribution due to neutrons will be (at saturation)

$$I = (1.6 \times 10^{-19}) \left(\frac{2.34 \times 10^6}{30}\right) \times VR\left(1 - \frac{1}{5}\frac{\Delta V}{V}\right) \text{ amperes} \quad (2)$$

where ΔV is the volume reduction accomplished by moving the chamber walls inward by a distance equal to the range of the alphas in the BF_3 gas. For BF_3 at atmospheric pressure, this range is about 0.3 cm.

The volume correction factor, $1 - (\frac{1}{5})\Delta V/V$, approximately accounts for the fact that capture events occurring near the walls may not contribute their full quota of ionization to the gas. The value of R from Eq. 2 may be used in Eq. 1 to evaluate the flux density, if one has a means of subtracting the portion of the ionization current that is contributed by gamma and other components of the field.

A particularly simple type of survey instrument (Fig. 1) consists of a pair of ionization chambers, each of about 3 liters volume. One is filled with pure, dry BF_3 to a pressure of about one-half atmosphere, and the other filled to such a pressure of argon or CO_2 as to give an ionization current identical to that from the BF_3 chamber when both are exposed to the same intensity of radium gamma radiation. These chambers are then arranged so that the difference current which exists in a combination slow-neutron and gamma field, by virtue of the alpha reaction in the BF_3, is fed into an electrometer with a sensitivity of about 10^{-12} ampere. The circuit is shown in Fig. 2.

It is to be noted that the chamber walls are not at ground potential, so a light-weight dural carrying case encloses them. The chambers are of brass, as thin as is compatible with their evacuation.

With a stable, bridge-type electrometer circuit, and a BF_3 gas filling enriched isotopically in B^{10} to 96%, flux densities in the range from 10 to more than 10^4 slow neutrons/cm²-sec are readily measurable. This is the range of interest in a region where the evaluation of safe working conditions is sought, such as the area immediately outside the shielding of an accelerator, or near an experimental facility at a reactor.

Foil-Activation Methods

Usually, survey work demands on-the-spot evaluations, so that direct-reading instruments involving the preceding methods are dictated. However, situations are occasionally met where accessibility problems, or problems of physical dimensions, require the use of the foil-activation method. The ideas and techniques have been described elsewhere (7, 8).

Of course, to accomplish absolute measurements of flux densities, knowledge is required of the activation cross section of the foils and of the absolute efficiency of the counting method. The latter will involve geometry, window absorption, and foil self-absorption studies. Because of these problems, it is best to employ the foils simply for comparison of neutron-flux densities, and if a region of known flux is available, it may serve as a reference standard.

The simplest way to achieve a region of known flux density is to place a Ra-Be neutron source of determined strength in a water tank of such dimensions that there are at least 30 cm of water in any direction from the source. A properly made Ra-Be source will yield 1.5×10^7 neutrons/sec per curie of Ra. At any distance, r, from the source which is emitting Q neutrons/sec, the thermal-neutron flux density is

$$\rho v_0 = Qf(r) \quad (3)$$

where $f(r)$ is the fractional number of neutrons emitted by the source which cross 1 cm² as thermal neutrons at distance r.

Curves of $f(r)$ have been prepared by various experimenters. The values of $f(r)$ given by Agnew *et al.* (9) are usable as given. From the data of Rush (10) one must construct a curve of $f(r)$ by dividing each datum point by r^2, and then normalizing so that

$$4\pi\sigma_H N_H \int_0^\infty f(r)r^2 dr = 1$$

where σ_H and N_H are the thermal

capture cross section for hydrogen, and the number of hydrogen atoms per cm³, respectively. This normalization is simply a statement of the fact that all neutrons emitted by the source are absorbed by hydrogen capture. The value of σ_H is 0.31 barns. In Fig. 3 is displayed such a curve calculated from the data of Rush (*10*). A certain amount of guess work is involved in extrapolating the curve to $r = 0$.

The element most used in foil work is indium, and the selection of thermal-neutron activation from that produced by both thermal and resonance capture is accomplished by measuring activation of the foils both with and without cadmium enclosure. The corrections due to Cd absorption of In resonance neutrons, and due to local depression of neutron flux density by the detecting foils, are discussed by Feld (7). These can be made small by proper design of the experiment.

Typically, the absolute counting efficiency for thin indium foils can be made such that thermal-neutron flux density is related to foil activity by

$$\rho v_0 = C(A - 1.07A_{Cd}) \qquad (4)$$

where C is a factor near 0.1, and A and A_{Cd} are the initial, saturated counting rates for the foils (in cpm) exposed uncovered and covered with Cd, respectively.

In summary, and for example, if one needs knowledge of the thermal-neutron flux density which would exist within biological tissue located in a given neutron field, one may imbed foil detectors in a tissue-equivalent medium (water does quite well in this case) of proper size, and determine the foil activation, with and without Cd envelope (0.020-in. thick Cd is sufficient). This activation is then compared with that obtained in a water tank with known flux as given by Eq. 3. Or, if counting efficiency is accurately calculated, so that the C in Eq. 4 is known, this latter formula may be used.

* * *

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The Care and Bleeding of Elephants

LARGE EXPERIMENTAL EQUIPMENT is commonplace in nuclear research. At the University of Rochester, work on the effects of ionizing radiations called for the use of an elephant. Here is a description* of the experimental arrangement, as set up by Mr. Strassle, a zoo keeper.

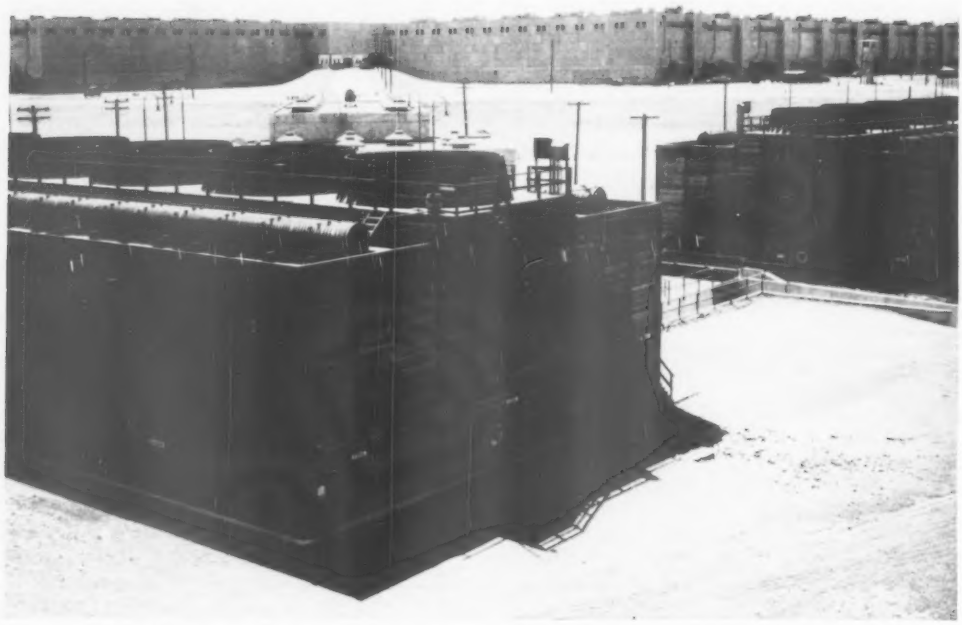
"At about 9:30 a.m. the group was escorted into Sally's two-room suite at Seneca Park Zoo. The elephant manifested considerable uneasiness at the approach of strangers.† Mr. Strassle energetically and skillfully maneuvered Sally into position so that she stood relatively quiet. This favorable situation was sustained by Mr. Strassle's feeding the elephant large handfuls of candy at regular intervals, the length of the intervals being determined largely by the speed with which Sally could swallow and reopen her mouth. Once or twice the candy supply ran out at crucial moments. Mr. Strassle saved the situation in these instances by thrusting his empty fist quickly into and out of Sally's mouth, after which Sally would swallow contentedly, *sans* candy. A fresh supply of candy was procured each time before the limits of Sally's gullibility were reached. It is estimated that the elephant ate one half bushel of candy in all.

"Inspection of Sally revealed that the veins in the ears were indeed large and superficial, and they would have been ideal for venepuncture except that (1) the ears were in constant vigorous motion, (2) Sally seemed to be quite apprehensive about having people even looking at her ears, and (3) the ear veins could have been reached only with the aid of a ladder. Further inspection suggested that the tail might be a suitable site for obtaining blood, since it was out of Sally's range of vision. Consequently, with one zoo attendant steadying the elephant's tail, 3–4 cc of 1% procaine were injected subcutaneously about half-way up the appendage. No vein could be felt through the extremely thick, tough skin, and after one or two attempts to aspirate blood into a syringe, the idea of venepuncture was abandoned, and blood was obtained by repeatedly sticking the tail vigorously in the procainized area with a No. 18 needle. Each time several large drops of blood flowed freely from the puncture site. The freely flowing drops were drawn up into pipettes and discharged a drop at a time onto coverslips for blood smears. Attempts were also made to obtain routine dilutions for red and white blood cell counts and hemoglobin determinations. The blood tended to clot very rapidly, however, and since smears received priority, not all the routine counts were obtained with desirable accuracy.

"The bleeding procedure was complicated only by Sally's attempts to sit down when the needle extended beyond the procainized area. This required critically timed prodding and shouting on the part of the tail attendant, and gave rise to a certain wariness of the entire tail-end crew, but otherwise was not a serious detriment to the experiment."

* From the University of Rochester Atomic Energy Project, Report UR-189; reproduced with permission of the director.

† This feeling, it should be noted, was mutual.



ENRICHED URANIUM FUEL, while it offers many advantages, is expensive. Producing it is a costly process; the cooling towers in the foreground are only a small part of the 60-acre gaseous diffusion plant at Oak Ridge, Tenn., where U^{235} is separated from U^{238}

PROGRESS REPORT

Military effort continues to dominate the reactor field. But this work is producing useful data on selection of fuel, coolant, and neutron energy for civilian power reactors

By K. H. KINGDON

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ARTICLES ON nuclear power, and this may be no exception, frequently merit the Churchillian paraphrase that seldom has so much been said about so little by so many. This deplorable circumstance is due partly to the fact that progress in nuclear power has been much less rapid than was envisioned by some enthusiasts a few years ago, and partly to the military secrecy which curtails reporting on this subject. However, both of these factors have been modified a bit during the last year or so.

The purpose of this article is to show the present status of nuclear power and the possibilities for the future.

Table 1 lists several important characteristics of reactors which have been constructed or which are in an advanced stage of engineering design or construction. (A more complete listing of reactors by H. Isbin was published in the March, 1952, NUCLEONICS, page 10.) These reactors are listed roughly in order of progress; that is, the Hanford reactors have been in operation since 1944, the Experimental Breeder Reactor has just gone into preliminary operation at the Reactor Test Station in Idaho, and an aircraft reactor for the atomic propulsion of airplanes is still some distance from realization.

Each of the reactor characteristics listed in the table will be discussed in turn. Progress in making these characteristics suitable for the production of useful power will be emphasized.

Fuels

The only fissionable material or nuclear fuel found in practical quantities in nature is natural uranium, a mixture of one part U^{235} which is fissionable, and 140 parts U^{238} which can be converted into fissionable plutonium in a nuclear reactor.

PLUTONIUM, like enriched uranium, is highly fissionable and therefore a concentrated fuel source. It too is expensive; only a small portion of the Hanford Works, Washington, where plutonium is produced by irradiation of natural uranium in nuclear reactors, is shown

on NUCLEAR POWER

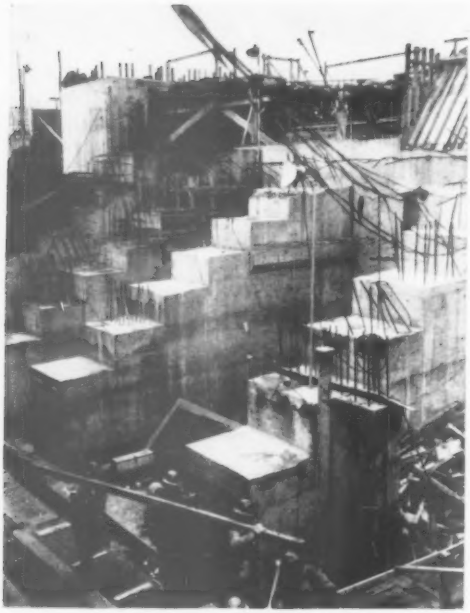
Most of the uranium used in the Western world at present comes from the mines at Shinkolobwe in the Belgian Congo district of Africa. Natural uranium is widely distributed throughout almost the entire world, but most of the deposits contain so little uranium that at present it is unprofitable to work them up into the finished metal. Workable deposits are found in various parts of Canada and in the Colorado plateau of the United States. These North American sources are being intensively developed to provide sources of uranium independent of those in the Belgian Congo.

It is now technically possible to recover substantial quantities of uranium from the accumulated waste piles of the gold mining area of South Africa, and a large program is under way to extract this uranium. It seems safe to say that adequate quantities of uranium are and will be available to the Western world for carrying out atomic energy development programs on any scale presently planned.

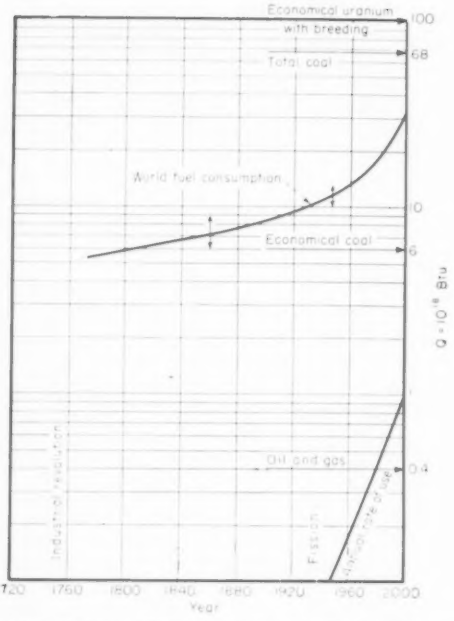
The raw ores are first refined and processed and then split into two channels. One of these takes the ore into production of uranium metal that is used as fuel for reactors, such as those at Hanford, in which plutonium is made. The other channel takes the ore into the production of uranium hexafluoride gas that goes into isotope

TABLE 1—Reactor Progress

Reactor	*Size*	*Fuel*	*Neutron energy*	*Coolant*	*Exit temperature*
Hanford		Natural U	Thermal	Water	$<100°$ C
Brookhaven	25 ft	"	Thermal	Air	$>100°$ C
"Clementine"	0.5 ft	Pu	Fast	Mercury	150° C
Experimental Breeder Reactor		Enriched U	Fast	Liquid Metal	Power
Materials Testing Reactor		"	Thermal	Water	$<100°$ C
Submarine Thermal Reactor		"	Thermal	Water	Power
Submarine Intermediate Reactor		"	Intermediate	Sodium	Power
Aircraft		"			Power



REACTOR using natural uranium as fuel is a large structure, as indicated by the massive, buttressed foundations for the Brookhaven reactor



WORLD ENERGY CONSUMPTION is constantly increasing, as shown by this data computed by Putnam for the AEC. With breeding, uranium will be a substantial addition to our sources of energy

separation plants for the extraction of the rarer isotope, U^{235}, which is then made into metal for various uses.

Natural uranium as fuel. A reactor using refined natural uranium as fuel is a large structure and, indeed, the active part of the Brookhaven reactor is roughly a cube some 25 feet on a side. Characteristic of most reactors fueled with natural uranium, this large size is determined principally by the requirement for bringing together enough fuel and moderator to make the reactor chain reacting.

Enriched uranium as fuel. To refine natural uranium, U^{235} is separated from U^{238} by the gaseous diffusion process which is based on the fact that gas molecules containing U^{235} are lighter and will thus diffuse more rapidly through porous membranes. Since many diffusion stages are required to separate the U^{235} completely, the process requires a large plant and is therefore expensive.

This separation and enrichment of U^{235}, however, brings with it certain advantages which more than justify the high cost of separation. In particular, it is possible to make reactors of very much smaller size than was the case for natural uranium reactors. For example, the Los Alamos "water boiler," has a reacting core that is only one foot in diameter. Indeed, the size of an enriched reactor is determined principally by the volume which is required to remove the amount of heat generated in the reactor.

This enriched nuclear fuel is a very concentrated source of heat, perhaps a million times as concentrated an energy source as coal. This makes it necessary to fabricate the enriched fuel in rather special ways to make possible the removal of the large amount of heat that can be generated by a very small quantity of fuel. In the water-boiler reactor, this special fabrication is accomplished very simply by dissolving a soluble uranium compound in water and by removing the heat from this solution by passing water through a coil of tubing placed within the reactor container. If the enriched fuel is to be used in solid form, quite elaborate fabrication into alloys and into thin plates or rods or tubes may be necessary.

Since the technology for separating the isotopes has been established, we can design and build reactors which will use any intermediate mixture of the U^{235} and U^{238} isotopes.

Plutonium, produced by exposure of natural uranium in a reactor, is a highly fissionable material just as enriched U^{235} is, so that it is also possible to construct small reactors that use plutonium. One such reactor, Clementine, is listed in the table of reactor progress.

Breeder reactors. The fact that fissionable plutonium can be made from U^{238} opens the avenue to what are called breeder reactors. It appears feasible to use the fission neutrons so efficiently in breeder reactors that not only will the chain reaction be sustained, but there will also be excess neutrons that can produce more plutonium from U^{238} placed in the reactor than is consumed in the chain reaction.

The breeding process brings with it the possibility of converting all of the relatively cheap and valueless U^{238} in the world into the valuable fissionable material plutonium. The operation of breeder reactors, and the chemical and

metallurgical manipulations incidental to the extraction of the plutonium produced in them, are expensive processes, so that plutonium, like U^{235}, is inherently rather expensive material. Nevertheless, both of these fissionable materials appear to be of the greatest future importance for the development of useful nuclear power. An experimental breeder reactor has just gone into operation at the Reactor Test Station in Idaho, and at KAPL a good deal of effort has been put into getting a quantitative understanding of the possibilities of breeding.

Future fuel demand. It appears that adequate quantities of uranium are and will be available for carrying out presently planned atomic energy development programs. But what is the probable future demand for nuclear energy?

To get some idea of whether nuclear energy will be needed as an adjunct to the world's present fuel supplies at any time in the near future, the AEC asked an engineer, Palmer Putnam, to make a broad study of the supply and consumption of fuel on a world basis. One of his first tasks was to establish a large unit of energy, since conventional engineering units of energy involve such small quantities of energy that computations become unmanageable. He picked a unit which he called *Q*, defined as equal to 10^{18} Btu.

All the energy consumed in the entire world during 1947 was equal to 0.1*Q*. Putnam studied the consumption of energy for all purposes throughout history and concluded that up to 1860, some 7*Q* had been used up. Note that the Industrial Revolution is commonly spoken of as having started in 1760, so that this amount of 7*Q* includes some 100 years of the Industrial Revolution. Up to 1947, the world had used a total of about 12*Q* and was consuming energy at such a rapidly increasing rate that Putnam estimated that by the year 2000, the world consumption of energy would have reached about 30*Q*.

These numbers should be compared with our known supplies of conventional fuels. Our known oil and gas reserves total only about 0.4*Q*. Even though new supplies of oil and gas are being discovered continually, it seems clear that they cannot be considered as a really major source of energy for the future. Our total known coal reserves are estimated to contain 68*Q*, but many of these coal deposits are uneconomical by present standards of working. It is estimated that the economical coal reserves are only 6*Q*.

If the world's demand for fuel and energy continues to increase at its present rate, we will be in need of new energy sources within a few decades. Present estimates indicate that economically available supplies of uranium, if much of the U^{238} is converted to plutonium by breeding, will constitute an addition to the world's supplies of fuel of the same order as the total coal supplies. Putnam has given a figure of 100*Q* for the total amount of energy available from economic uranium, with breeding. Of course, it is likely, as has been pointed out frequently, that solar energy will be developed for economical use as time goes on, so that among coal, uranium, and the sun, the world's needs for energy will be met.

Neutron Energies

As indicated in Table 1, reactors have been built using neutrons of different energies or speeds. The choice of neutron energy is made to fit the particular type of reactor under design. For example, the Experimental Breeder Reactor uses fast neutrons to explore the potentialities of fast neutrons in the breeding process. Fast neutrons are much less strongly absorbed by all substances than are slow neutrons, so that the use of fast neutrons gives one much greater freedom in the kinds of materials that may be included in the reactor. Clementine uses fast neutrons, and it is possible to employ mercury as a coolant because the fast neutrons are only slightly absorbed by the mercury.

Effect of energy on control. The methods for controlling a reactor vary with the predominant neutron energy, so that a method of control must be chosen which is suitable for the particular neutron energy. Most of the reactors which have been constructed to date employ slow or thermal neutrons. As a result of this, thermal-neutron reactors are somewhat better understood at present than are the reactors using the faster neutrons.

Coolants

Several different coolants have been used in reactors since the war; water, air, and liquid metals have all been used. Liquid metals include such things as mercury, bismuth, sodium, and the low-melting alloy of sodium and potassium.

Most of the reactors in Table 1 have been operated at rather low coolant exit temperatures, but presumably the temperature of the air coming from the Brookhaven reactor or the temperature of the mercury from the Fast Plutonium Reactor would be high enough to generate power at rather low efficiency. Of the reactors that avowedly have power generation as an objective, the Submarine Thermal Reactor uses water as a coolant, while the Experimental Breeder Reactor and the Submarine Intermediate Reactor both use a liquid-metal coolant.

Water as a coolant. Water has been the most frequently used reactor coolant and is, in fact, used in the large plutonium-producing reactors at Hanford. In a water-cooled reactor the hydrogen in the water will slow down the neutrons so rapidly to thermal energies that any water-cooled reactor must operate with thermal neutrons. This is an undesirable restriction, so that coolants other than water are under investigation. In addition to this, water boils at quite low temperatures so that, if one attempts to operate a water-cooled reactor at high temperatures for power production, one must be prepared to cope with high pressures within the reactor structure. This is done in the Submarine Thermal Reactor, but the presence of a high pressure in the reactor brings with it certain obvious difficulties.

Air as a coolant. Air has been used as a coolant in a number of reactors, including the Brookhaven reactor. Air, on account of its low mass per unit volume and its low thermal conductivity, is a relatively poor coolant compared with water, so that in an air-cooled reactor large areas must be provided for heat transfer, the surfaces of the fuel elements over which the air flows must be at relatively high temperature, and there must be a relatively large temperature differential between the fuel element and the coolant air. These same comments apply in lesser degree to helium used as a coolant, and so far no helium-cooled reactor has been built.

Liquid metal as a coolant. Turning to the liquid-metal coolants, a good deal of attention has been given to the alkali metals. Sodium reacts violently with water. But in using sodium as a

TABLE 2—Relative Pumping Powers for Coolants

Coolant	*Relative pumping power*
Bismuth	1.00
Lead	1.31
Sodium	0.20
Mercury	1.07
Helium (10 atm.)	5,400
Air (10 atm.)	11,900
Water vapor (10 atm.)	3,800

coolant, it is entirely possible to avoid bringing it into contact with water, and in most other respects sodium has highly desirable properties.

Sodium is readily available. It is well known in the chemical industry; in 1949, 70,000 tons of sodium were produced in the United States at a price of about eighteen cents a pound.

Sodium has high thermal conductivity and low vapor pressure so that it can be used to transfer heat at high temperature inside a reactor without giving rise to any accompanying high pressures. This makes the mechanical construction of the reactor easier than is the case when the pressures are high. Sodium has low density and high thermal conductivity, so that only a relatively small amount of power is needed to pump enough sodium through the reactor. This is a property shared to some extent by all liquid metals, as shown in Table 2, so that the pumping power required for a reactor cooled by liquid metal is very much smaller than that required if the reactor is cooled by air. We have carried out extensive investigations at KAPL on sodium as a reactor coolant and have learned how to purify it, how to pump it around a heat transfer circuit, and how to handle it safely in relatively large installations.

Economics of operating temperature. The fission reaction could supply heat in a reactor at very high temperatures, but on account of limits set by the endurance of the structural materials, power reactors will first be operated with the lowest possible temperatures consistent with the service demanded in supplying power. On the other hand, it is well known that the efficiency of a power plant increases with the temperature so that, from the point of view of economic power and efficient power, there is an urge to raise the temperature. Some rough comparisons of the effect of steam temperature on power cost are shown in Table 3 which compares the cost of the steam and electrical generating equipment for generating electricity at 750° F and 325° F. The cost is about 20% higher at the lower temperature, so that the economic penalty for operating the first power plants at low temperatures is not prohibitive.

The mobile military reactors and the Experimental Breeder Reactor will be the first ones to operate at the higher temperatures which are more suitable for power production.

Handling of Materials

One other field of progress must be considered—the development of methods for handling intensely radioactive materials. Many of the materials that have been inside a reactor are so strongly radioactive that they cannot be handled manually or with laboratory tongs even for periods of seconds without harming the worker by the powerful radiations emitted. Accordingly, it is necessary to develop handling equipment which can be operated remotely from behind a shield sufficiently thick to absorb all radiation. This type of radioactive work moves rather slowly, and frequently an operation which might take a minute under ordinary conditions of manual working will require an hour by remote control.

Military Nuclear Power

Thus far this article has reviewed progress in the development of useful nuclear power. There are two major objectives of this development—the development of mobile military power plants, and the development of truly economic nuclear power such as might be employed by industry or by a public utility.

The military interest in atomic power for ships and airplanes stems principally from the highly concentrated nature of atomic fuel. Military considerations frequently demand that a vehicle shall be able to maintain high speed for a long time, and both these requirements are made available by using a concentrated fuel. The need for high speed makes particularly severe demands on the fuel supply. To double the speed of a ship requires an expenditure of eight times as much power. Nuclear fuel, with its million-fold greater concentration of energy over conventional fuels, is a natural for such military applications.

In addition to this, nuclear fuel does not require combustion with air to liberate its energy. This characteristic of the fuel will enable a nuclear-powered submarine to remain submerged for long periods of time. On the other hand, this ability to deliver its energy without an air supply for combustion is not of particular importance for a nuclear-powered jet-propelled airplane, because air is needed to make the propelling thrust of the jet, and the turbo-jet compressor ordinarily supplies much more air than that required for combustion of conventional chemical fuels. Hence the interest of nuclear fuels for airplanes lies entirely in the long range without refueling which the concentrated nature of nuclear fuel makes possible.

These technical considerations are the factors which suggest the use of atomic fuel in mobile military power plants. Economic considerations are of secondary importance only. It is not too important what the cost of power on a jet plane is, but rather that the plane be able to fly longer, faster and higher than its competitors. This lack of emphasis on cost is a fortunate circumstance for the military applications of nuclear power, for like most new things, nuclear power will be expensive at first.

The most important features of a mobile military nuclear power plant are reliability, compactness, and light weight. A great deal of attention is being given to these features in the plants under development. The requirement for a biological shield to contain the dangerous nuclear radiations within the power plant of an inhabited vehicle makes the requirement of light weight a particularly difficult one to satisfy. This is especially so because there is nothing very smart that one can do about absorbing gamma rays, which can only be absorbed by relatively large thicknesses of heavy materials. These thicknesses

TABLE 3—Temperature and Power Cost

Steam temperature (°F)	750	325
Steam pressure (psi)	485	200
Relative plant cost/kw	1.00	1.18
Relative power cost	1.00	1.22

are of the order of a few feet for materials like water and concrete, and of the order of a few inches for a very heavy material like lead. Fortunately, although the weight of shielding needed for an inhabited vehicle is awkward, it is not prohibitive.

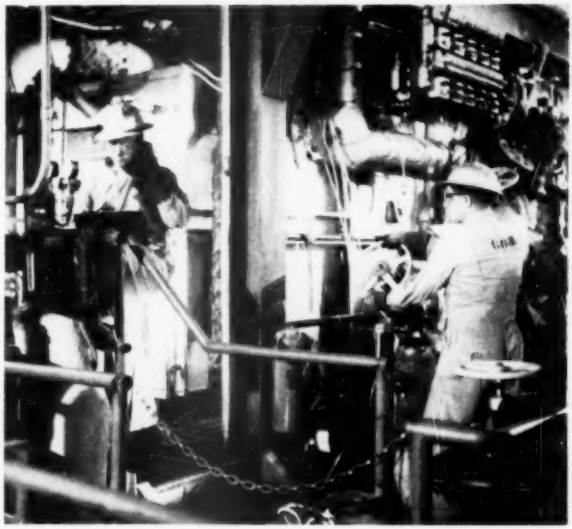
The requirements of reliability and compactness are not unique to the nuclear power plant but are shared by any other mobile military power plant. The reliability requirement is made somewhat more difficult by the obvious problems which would attend maintenance or repair of any component of the plant which had become radioactive, and also because the nuclear requirements of the plant may demand the use of unusual coolants or structural materials with which there is little or no industrial experience. It almost seems sometimes as if all you have to do is to name the nastiest and most difficult substance to work with that you can think of, and it turns out that this is just the finest thing to use in a nuclear power plant.

There is also the question of the damage which may be done to the materials in the power plant by the intense nuclear radiations, damage which may be serious enough to cause failure of some component. Extensive investigations are being made of this radiation damage. It appears that neither the unfamiliar materials with which one has to work, nor the effects of radiation on the materials of the plant, is likely to prove to be a prohibitive limitation on the development of mobile military nuclear power.

Economic Nuclear Power

Economic and industrial interest in nuclear power stems primarily from the simple fact that here is a new source of power of substantial amount, which may eventually produce power cheaply.

In considering this, we must recall again that nuclear fuel is simply a new source of heat and that all the other costs of converting conventional fuels into electricity will have to be borne by a nuclear power plant in equal or greater amount. The comparison between the cost of nuclear fuel and the cost of coal is, therefore, of fundamental importance for this application of atomic energy. We shall limit ourselves to the cost of enriched nuclear fuel, both because this is the kind of fuel with which experience is being gained in connection with the mobile military plants, and because enriched fuel is of particular interest for power plants in which the attempt is made to produce additional nuclear fuel by breeding.



LIQUID METALS are excellent heat-transfer materials for obtaining power from a reactor. Sodium, a readily available metal, has been successfully handled in the pilot plant shown here

One gram of enriched nuclear fuel can produce about 20,000 kw-hr of heat energy which may be converted to about 6,000 kw-hr of electric energy in a reasonably efficient generating plant. The cost of coal needed to generate 1 kw-hr of electrical energy varies widely in different localities, but a cost of 0.2 cent will not be grossly in error for our purposes. This figure, multiplied by the 6,000 kw-hr, will give us $12 as the value of a gram of enriched atomic fuel for generating useful nuclear power, provided that the nuclear reactor and power plant are no more expensive than the conventional coal plant. Preliminary estimates indicate that the nuclear plant will indeed be somewhat more expensive than the conventional plant so that the practical power value of our enriched nuclear fuel must be still further reduced, perhaps to $8 per gram.

Various estimates have been given of the cost of producing enriched nuclear fuel. All of them are substantially higher than $8 per gram. It is clear that the infant nuclear power industry has a major job to do in making its enriched fuel more cheaply and in designing the cheapest possible plants for using it.

There are some other considerations that may make this balancing of the nuclear power budget a little easier. Industrial uses of fission products produced in nuclear reactors are being explored. A comprehensive AEC-sponsored paper study has been completed by Stanford Research Institute (NU, Jan. '52, p. 45), and many preliminary application studies are underway. Such uses of fission products would be of permanent help in making a nuclear power industry economically self-supporting.

A much more important possibility stems from the fact that a nuclear power plant could produce plutonium or other nuclear fuel as a by-product of the making of power. The discussion up to now has assumed that this plutonium only has value as fuel for generating more electric power. But so long as the present military and political situation continues, it has a much greater value as bomb material, and the manufacture of bomb plutonium by the nuclear power plant offers at least transitory assistance in balancing the budget.

* * *

This article is based on an address presented before the Royal Canadian Institute, Toronto, Canada, January 26, 1952.

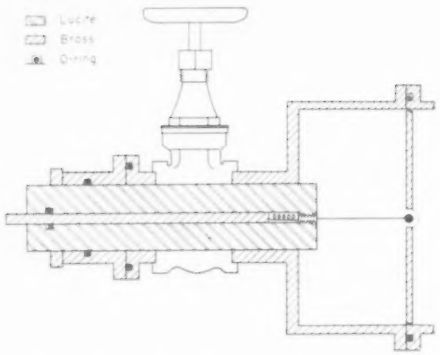


FIG. 1. Cross section of the source end of the magnetic-lens spectrometer

The accelerating potential is applied at the external left end of the central brass rod. The Lucite acts as an insulator between the high voltage and the electrically grounded exterior of the spectrometer. The entire structure encased in the Lucite slides into place through the gate valve, which is a Crane water valve modified for vacuum in accordance with the principles described by Kurie (2). A circumventing ring of brass at the extreme left end is fastened to the Lucite and acts as a positive stop for the sliding structure in order to insure that the spherical source holder, held by a thin rod screwed into the right end of the Lucite, is concentric with the electrically grounded grid. The grounded brass disk, at the center of which the grid is located, acts also to prevent any stray electric field from reaching the main portion of the spectrometer, which is located further to the right.

Relative Transmission of Beta Particles Through G-M Counter Windows

For counter design, it is important to know the transmission characteristics of window materials. The method of measurement described here uses the acceleration of betas at the source of a magnetic-lens spectrometer

By CHIA-HUA CHANG and C. SHARP COOK
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THE PASSAGE of electrons through matter has been for many years a problem of interest. In this laboratory one of the chief reasons for desiring information of this type concerns the problem of determining the relative transmission of beta particles through the windows of Geiger-Müller counters.

Since the relationship between the number of beta particles actually entering the sensitive region of the G-M counter, and the number impinging upon the outer surface of the window of this counter, depends both upon the absorption and upon the scattering of the particles within the window, the relationship is not easily obtained from theoretical considerations. The existence within the laboratory of a device for experimentally determining this ratio is of considerable

value. This paper describes a method that uses a normal magnetic-lens spectrometer for the purpose of testing the electron-transmission characteristics of the window of a Geiger-Müller counter.

Apparatus

Electrostatic acceleration at the source of a spectrometer is generally considered unsatisfactory because the shape of the resulting electrostatic field is usually such that it distorts the shape of the true beta spectrum. To eliminate the possibilities of such field distortion, acceleration of the beta particles as they pass from the spectrometer exit slit into the G-M counter window has been attempted (*1*). However, upon application of high voltage, a very large number of superfluous counts were always observed and could not be eliminated.

In the present experiment, the window transmission is measured by a method that uses the acceleration of beta particles from the source of a magnetic-lens spectrometer. The potential applied to the source is always negative. It will therefore accelerate negatrons and decelerate positrons. All discussions in the text will be made applicable to negatrons. In the case of a positron spectrum, the application of a negative potential of 5 kv will shift the spectrum by 5 kev toward lower energies.

The problem of spectral distortion by the electrostatic field is greatly reduced through use of a spherically shaped source, as illustrated in Fig. 1. To preserve the necessary symmetry and thus prevent, or greatly reduce, the amount of spectral distortion, the source material is electroplated uniformly over the forward hemisphere of the source holder, which is made of copper. Concentric with this source, and surrounding it very closely, is an electrically grounded mesh of fine wire. This whole structure acts as the spectrometer source.

To provide a uniform source which will make good electrical contact with the source holder, it is also necessary that the selection of sources take into consideration the electroplating properties of the material. To date Cu^{61} has been used as the positron source and Ag^{110} as the negatron source. Each can be easily electroplated in a uniform manner.

Otherwise the spectrometer is of the customary magnetic-lens type. The counter is surrounded by a 1-in.-thick lead shield to reduce extraneous background.

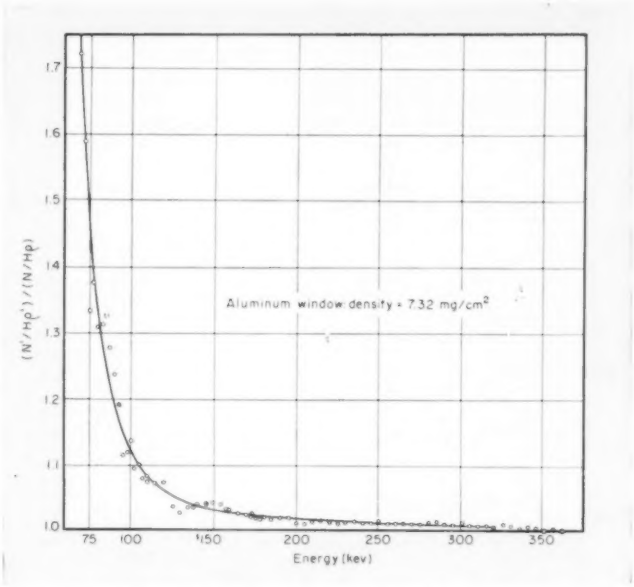

FIG. 2. Ratio of the spectral counting rates at $E + 5$ and E

Experimental Method

In theory, the method for determining the G-M window transmission is rather simple. A source is chosen whose beta spectrum covers an energy (momentum) range extending at least to the point of complete (100%) transmission for the G-M counter window under study.

With the source holder electrically grounded, a given spectrum is recorded by the spectrometer counter. In the lower energy (momentum) regions, the intensity of the beta-particle spectrum is reduced because of absorption and scattering within the window of the G-M counter. The number of beta particles which pass through the window and are recorded by the counter depends upon the energy of the impinging particles; the higher energy ones have a larger probability of being recorded.

If a negative accelerating potential is applied to the source holder, the beta spectrum will be shifted by the amount of the applied voltage (say 5 kv) toward higher energies, and that part of the spectrum whose beta particles normally are emitted with a kinetic energy of E kev will, after the voltage application, be emitted with a kinetic energy of $E + 5$ kev.* Thus, because of the increase in energy, the number of particles recorded from this part of the spectrum will be increased upon application of the accelerating potential at the source.

To obtain the true increase in the number of recorded particles, one must correct for the transmission characteristics of the spectrometer by dividing the number of recorded particles, N, by the electron momentum, $H\rho$. This gives the true spectral counting rate, $N/H\rho$. This is a standard technique required because of the characteristics of all magnetic spectrometers.

Since, upon application of an electrostatic potential to the source, the

* The use of Cu^{61} leads to a difficulty in the region of the internal conversion line associated with the gamma-ray transition at 76 kev (*3*). The use of a negative potential on the source will of course shift the electrons associated with the internal conversion line toward higher energies while the underlying positron spectrum is being shifted toward lower energies. This region of the Cu^{61} spectrum, therefore, cannot be used in the measurements.

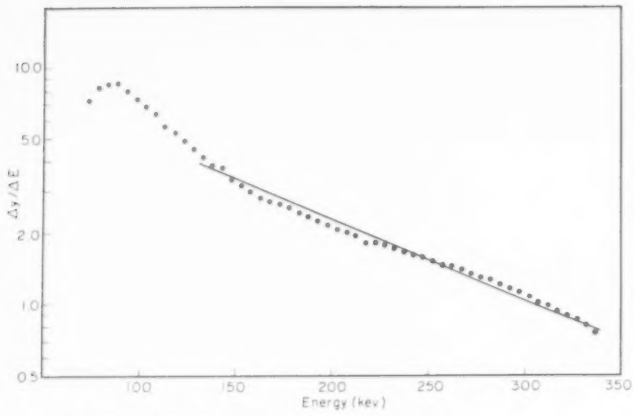

FIG. 3. Data of Fig. 2 plotted on a semilogarithmic scale

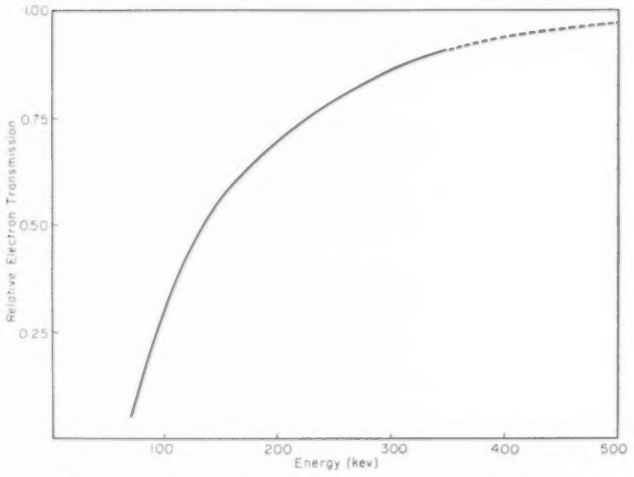

FIG. 4. Relative electron transmission, η, for Al foil with density of 7.32 mg/cm²

change in recorded counting rate for any given point on the spectrum is due solely to the difference in transmission characteristics of the G-M counter window at these two energies, this difference in counting rate can be used to calculate the relative transmission of the window for beta particles.

Figure 2 shows a curve of the ratio

$$\frac{(N'/H\rho')_{E+\Delta}}{(N/H\rho)_E}$$

for an aluminum window having a surface density of 7.32 mg/cm². The primed quantities were determined at times when 5 kv was being applied to the source, while unprimed quantities apply to spectral values determined with the source electrically grounded. Thus, both numerator and denominator of the ratio are recorded intensities associated with the same point on the beta spectrum, but under the condition that the spectrum has been shifted by 5 kev between the two readings.

Each experimental value used in Fig. 2 represents the relative increase in transmission of the window for a constant-intensity monoenergetic group of electrons whose energy has been increased by 5 kilovolts.

If a best smooth curve is fitted through the experimental points of Fig. 2, and a plot of the results made on semilogarithmic paper, as in Fig. 3, the higher-energy portion is found to approximate a straight line. The significance of this straight line is that the higher-energy part of the transmission curve approaches unity (100% transmission) approximately in an exponential fashion. This is mathematically expressed in the form $\eta = 1 - Ke^{-CE}$, where η is the transmission coefficient, E is the electron energy, and C and K are constants.

Theoretically, then, the data plotted in Figs. 2 and 3 should be the differential of the transmission curve, $d\eta/dE = CKe^{-CE}$. However, the actual quantities plotted are something which must be represented mathematically as $\Delta y/\Delta E$, where the quantity Δy represents the change in window transmission for an increment change in energy, ΔE, of 5 kv.

If the quantity ΔE is small compared with E, it is then possible to approximate the term $\Delta y/\Delta E$ with its differential form dy/dE. In such a case the differential dy/dE will be of the same general form as $d\eta/dE$, written however in the form $\Delta y/\Delta E = BCe^{-CE}$, where the constant B temporarily replaces the constant K in the equation for $d\eta/dE$. The reason for this is that, to make a plot of the integrated curve, the value of y must be arbitrarily chosen at some energy E. Thus the asymptotic value approached by the quantity y at higher energies is not necessarily unity, but some constant A. The integral curve thus determined must then be expressed mathematically as $y = A - Be^{-CE}$. However, it is seen that η may be immediately derived from this merely by division of the equation by the constant A, so that $\eta = y/A = 1 - (B/A)e^{-CE}$. Such a curve for the 7.32-mg/cm² aluminum window is shown in Fig. 4.

Limitations

Saxon has recently compiled (4) most of the known data on transmission coefficients. He expresses his results as a correction factor, $1/\eta$ (the inverse of the transmission coefficient),

which is the factor by which the recorded intensity must be multiplied to obtain the true intensity. Figure 5 records the fact that our data, although for a thicker window, give a curve of the same general shape as that recorded for the thickest window considered by Saxon in his compilation of transmission-coefficient data.

In the current series of experiments the authors have found three important limitations. Two of these have been mentioned briefly earlier in the text.

In the first place, the over-all size of the effective source (this includes both the sphere upon which the radioactive material is electroplated, and the electrically grounded grid concentric with this sphere) should be no larger than any other source regularly used in the spectrometer. This is necessary in order that the electrostatically accelerated electrons be emitted isotropically. If the grounded grid is too far removed from the copper sphere, there exists the possibility that the spectrometer's magnetic field will not act exclusively upon the beta particles in an electrically field-free region, but will also act upon the electrons within the region of electrical acceleration, thereby distorting to some extent the recorded spectrum of the beta particles.

It is also because of the necessity of an isotropic distribution of beta particles beyond the grounded grid that the source is electroplated uniformly over the entire forward hemisphere of the source holder. With the electrostatic field applied only in a radial direction, but with beta particles being emitted isotropically from any single point, a change in direction of a single beta particle caused by this electric field must be compensated for by an appropriate change of direction of a beta particle from some other part of the source. With a uniform electric acceleration over the entire hemisphere of a uniformly distributed source, an initially isotropic distribution of beta particles should remain an isotropic distribution.

The other basic limitation mentioned earlier in the text applies to a sufficiently small choice of ΔE, such that it may be approximated by the differential form dE. The 5-kev interval chosen for this quantity seems appropriate for the thickness of windows currently under consideration. However, a smaller interval would be even better. A choice of a smaller energy interval, though, will exaggerate the third limitation, which will be mentioned later.

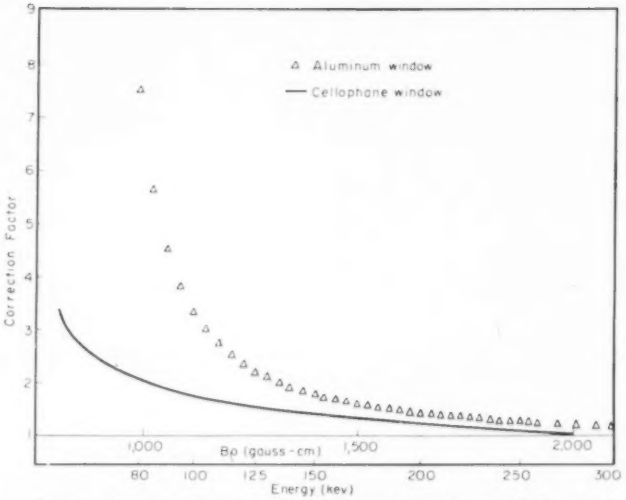

FIG. 5. Correction factor, $1/\eta$, for aluminum window of density 7.32 mg/cm^2, and for cellophane window of density 2.0 mg/cm^2 (2)

One must therefore choose a value for ΔE appropriate to the experiment. When measurements are made on thinner G-M tube windows, values must be chosen such that they are small compared with E. It will therefore be necessary to make ΔE less than a kilovolt for thin Zapon windows. A technique not yet tried, but which might be useful, is to use a continually changing value of ΔE in order to keep its magnitude percentagewise always the same with respect to E.

The third limitation on this method concerns the matter of statistics. Except for that region very close to the low-energy cutoff* of the window, a small shift of the spectrum along the energy axis, by an amount ΔE, will produce only a very small change in the counting rate, ΔN. To record any real effect, it is therefore necessary to reduce the statistical error to a value smaller than this change in counting rate.

This limitation results in the requirement that there be a large number of recorded counts for each experimental point. As mentioned above, this is not independent of the energy increment, ΔE, which is chosen, since smaller increments produce smaller differences in counting rate and, as a result, produce a situation which requires large numbers of recorded counts. To provide acceptable results, especially with a substance of short half-life, such as Cu^{61}, this combination of limitations indicates also the need for a strong source. Some sort of happy medium must be accepted.

These requirements, along with the accepted policy that the source be electroplated to the source holder in order to insure the same applied voltage at all points in the source, may severly limit the general adaptability of the method in some instances. However, when applied with proper caution the method should prove quite useful.

* * *

This work was assisted by the joint program of the Office of Naval Research and the Atomic Energy Commission.

* Defined as that energy below which there is no beta-particle transmission.

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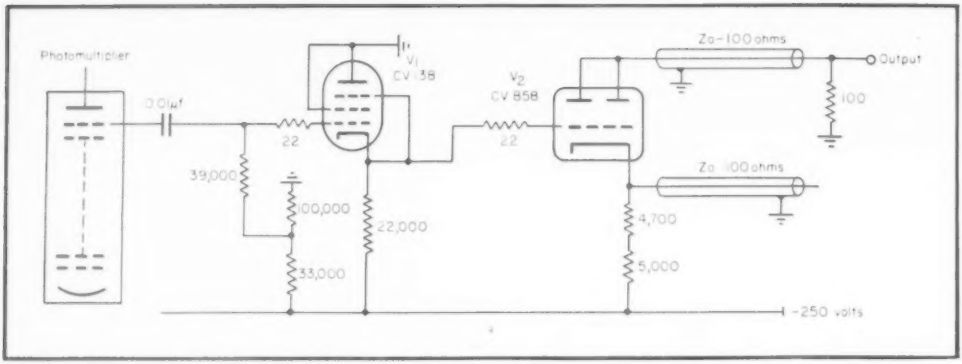

FIG. 1. Pulse forming circuit for scintillation counter

Fast Pulse Circuit Techniques for Scintillation Counters

Increased operating speeds result when secondary-emission pentodes are used in fast circuits. Besides circuits for scintillation counting, circuits have been designed for testing, calibration, and for displaying results

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THE APPLICATION of fast pulse-type circuits to scintillation counting is chiefly confined to fast scaling, coincidence, and amplitude-discrimination circuits. In addition, pulse generators, oscilloscopes and amplifiers are required which can be used for simulating, displaying and amplifying pulses obtained from scintillation counters.

Fast Scaling

Fast scaling is made possible by using voltage pulses of short duration. Spurious pulses, however, can cause significant errors, and must be guarded against.

Pulse shaping circuit. The output pulse from a scintillation counter must be transformed into a voltage pulse of short duration before fast scaling and amplitude discrimination become possible. This is usually done by allowing this output current to flow through a low resistance (shunted by the output stray capacity) and then amplifying the resultant voltage pulse. This method gives a rather sharply peaked waveform.

An alternative method is to allow the scintillation-counter output current to flow into the output stray capacity shunted by a high resistance, thus producing a step-type voltage waveform, and then to follow this by a delay-line pulse-shaping circuit. This gives an output pulse of approximately rectangular shape with a controlled pulse duration. A circuit of this type (*1*), used at AERE is shown in Fig. 1. The pulse-duration control is achieved by the open-circuited coaxial cable in the cathode of V_2. The cathode-follower V_1 is used to give a low-impedance grid-driving waveform to V_2. The internal cathode impedance of V_2 is chosen to be approximately the same as the characteristic impedance of the coaxial cable.

The output from the anode of V_2 is a negative voltage pulse; this is further amplified before being applied to the following scaling or other types of measuring circuits.

Spurious pulses. The standard fast scaler used at AERE consists of an amplitude discriminator followed by a scaling circuit, the time resolution of the discriminator being 0.25 μsec. The scaling circuit will count all the output pulses from the discriminator circuit. Considerable trouble has been encountered recently with scintillation counters when using this scaler. This trouble can be attributed to spurious pulses occurring immediately after the true pulse.

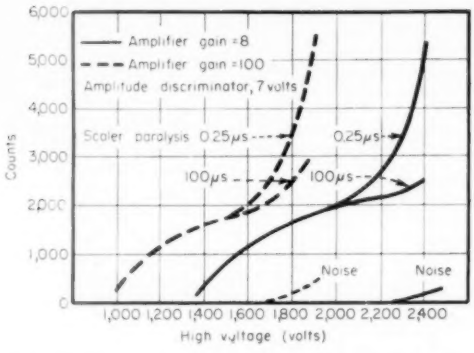

FIG. 2. Counting rate as a function of high voltage for EMI 5311 photomultiplier used with stilbene and cobalt-60 source

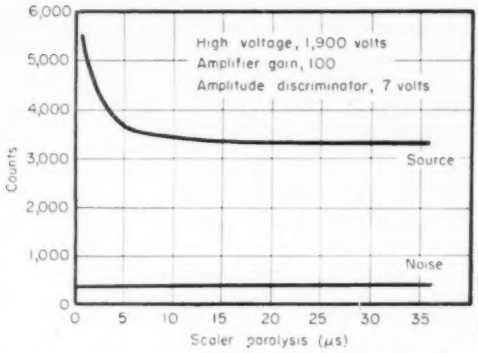

FIG. 3. Counting rate as a function of scaler paralysis for EMI 5311 photomultiplier used with stilbene and cobalt-60 source

Figure 2 shows some curves of counting rate versus high voltage for a scintillation counter with a γ-ray source. These curves show the difference between the counts registered by a fast scaler and by a scaler with a long paralysis time after each registered count. The paralysis time of this latter scaler is sufficient to reject most of the spurious pulses. As the high voltage on the photomultiplier is increased from the minimum, the two scalers register the same counts until the spurious pulses become large enough to pass the amplitude discrimination level. Thereafter the fast scaler will count both true and spurious pulses, thus giving considerable errors. The curve of count rate versus scaler paralysis time in Fig. 3 shows that the majority of these spurious pulses occur within 5 μsec after the initial pulse.

These results emphasize the need of careful checking of fast scaler counts to ensure that no spurious counts are registered. In those cases where the average count rate may be temporarily reduced, an auxiliary scaler or count-rate meter with long paralysis time may be used to check the results of the fast scaler. To achieve this simply, a paralysis time of about 2 μsec may be switched into circuit in the latest design of fast scaler at AERE.

Pulse Generators

Besides pulse generators for general testing of circuits, special apparatus is needed to provide a pulsed source of radiation for testing the complete counter. In addition, a pulse generator is needed that will duplicate the output of the photomultiplier.

Pulse simulators. During design of circuits associated with scintillation counters, it is desirable to have a pulse generator, of moderately high recurrence frequency, to produce pulses similar to those obtained from a scintillation counter. A recurrence frequency of the order of 10 kc is used at AERE to facilitate observation of the pulse waveforms with oscilloscopes.

One method is to use an X-ray tube which is pulsed into current by an auxiliary pulse generator. This pulse generator is used in those cases where it is necessary to test the photomultiplier in conjunction with the circuits.

A pulse duration of between 10 and

LATEST DEVELOPMENTS IN SCINTILLATION COUNTING

This article and the one by G. G. Kelley on page 34 are the first two of a series based on presentations at the Scintillation Counter Symposium, Washington, D. C., January 29-30, 1952. Additional articles will be published in suceeding issues of NUCLEONICS; these will include:

"Solid and Liquid Scintillation Counters," by G. T. Reynolds
"Pulse-Height Resolution and Photosensitivity," by R. K. Swank
"Afterpulsing in Photomultipliers," by D. W. Mueller
"Performance of Pulsed Photomultipliers," by R. F. Post
"Temperature Effects in Organic Scintillators," by S. H. Liebson
"High-Energy Particles and the Scintillation Counter," by L. F. Wouters
"Neutron-Detecting Phosphors," by J. C. Schenck
"Two New Photomultipliers for Scintillation Counting," by M. H. Greenblatt, M. W. Green, P. W. Davison, and G. A. Morton.

A summary of the symposium, including discussions, was published in March, 1952, NUCLEONICS, pages 32-41. On page 36, in the discussion "Properties of organic scintillators," the name of the senior author, R. C. Sangster, was omitted; in Fig. 6, on page 37, the unshaded bars are for $-70°$ C, not 70° C; highly purified, essentially monocrystalline samples were used.

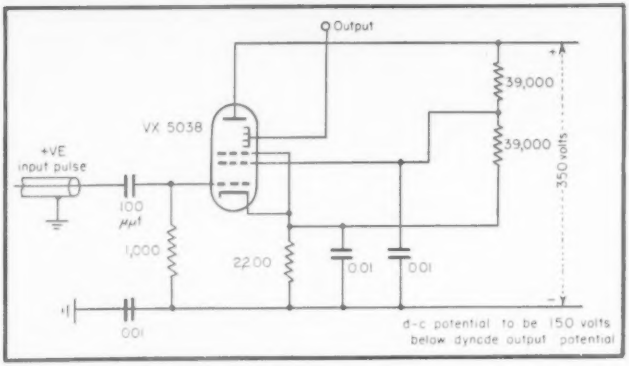

FIG. 4. Scintillation-counter pulse simulator

50 mμsec may be used. A small X-ray tube which has been used for this purpose employs 25 kv on the target plate; the X-rays emerge through a thin window in the glass wall.

To test the circuits without the photomultiplier, it is sometimes necessary to produce a pulse of current simulating the output of the photomultiplier with a minimum of alteration of the output-circuit impedance conditions. A secondary-emission type of pentode may be used for this purpose as shown in Fig. 4. This pentode is normally biased off and then pulsed into current with a pulse of duration between 10 and 50 mμsec derived from an auxiliary pulse generator. The dynode current and anode current of this pentode may then be used to simulate the output current from the final dynode and collecting anode of a photomultiplier.

Double pulse generator. A double pulse generator has been recently designed for general testing of coincidence units and fast scalers. This generator gives output pulses with rise times of about 8 mμsec and pulse durations of 0.05, 0.25 or 1 μsec. The pulse producing circuit is shown in Fig. 5.

This circuit was derived from the one designed by Moody and uses an EFP60 type of secondary-emission pentode. Positive feedback from anode to cathode is used instead of the dynode-to-grid feedback in Moody's circuit to allow the grid to be used for the trigger input pulse. The anode delay line controls the pulse duration, and the feedback capacitor from anode to cathode must be chosen such that with the delay line terminated in its characteristic impedance, instead of short circuited, the pulse duration obtained from the circuit is about three times the required pulse duration.

A positive pulse is taken from the dynode output. This pulse is limited in amplitude by the point-contact germanium crystals before being passed through the output tube. When germanium crystals are used in this manner as voltage regulators, there is a time of the order of 10 mμsec between the application of a pulse and the crystals taking their full forward current.

The forward resistance of these crystals appears to change in a truly exponential manner from the initial high value to a final value corresponding to the applied forward voltage, the time constant of this change being of the order of 10 mμsec.

This effect would produce an overshoot after the leading edge of the dynode output pulse from the EFP60 tube in the circuit of Fig. 5, but this can be compensated by the addition of resistance R_2, shunted by the capacitor C_2, in series with the crystals. The time constant R_2C_2 is chosen by experiment to give the optimum shape of the final output pulse from the CV2127 tube.

The CV2127 output tube is normally biased off and then pulsed into current by the output of the EFP60 tube, thus

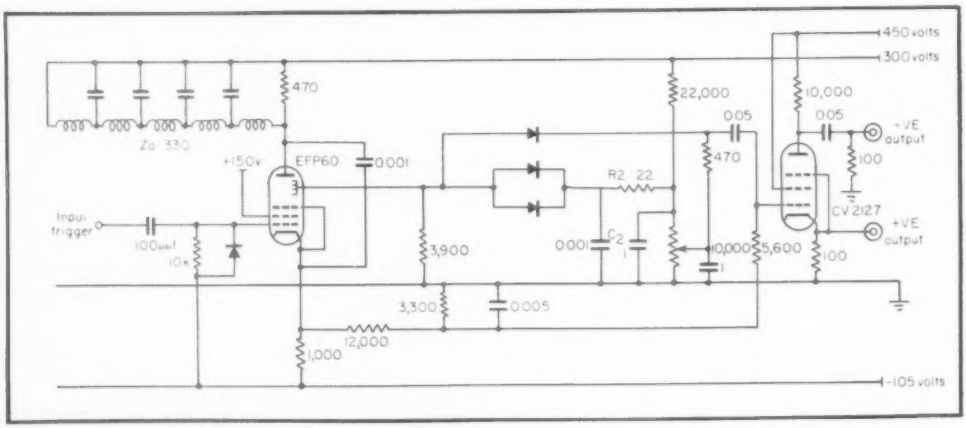

FIG. 5. Fast pulse generator

giving a positive output pulse from the cathode and a negative output pulse from the anode.

Amplifiers

Secondary-emission pentodes have been found to meet the requirements imposed on amplifier design by the characteristics of scintillation-counter pulses. These tubes make it possible to avoid overloading in wide-band amplifiers and to reduce amplifier delay time in distributed amplifiers.

Overload conditions. The design of wide-band amplifiers for use with scintillation counters must take account of the wide range of input pulse amplitudes that may be present. In particular, the amplitudes of any positive pulses applied to the grids of an amplifier stage should not be large enough to give grid current. This trouble may easily occur in the last few amplifier stages since there may be at least a 20-to-1 difference in amplitudes between the largest pulse and the smallest pulse to be amplified by the circuit.

To avoid this trouble the positive pulse output from any amplifier stage (except the output stage) should be limited to a sufficiently small amplitude to ensure that no grid current flows in the subsequent stages. This limiting is achieved in the AERE distributed amplifier design by limiting the number of tubes in any stage which supplies a positive output pulse such that if all the tubes are completely cut off by a negative input pulse, the total change of anode current will give a positive pulse whose amplitude is insufficient to drive the following stage into grid current. The tube type required is one that will give the maximum mutual conductance with the minimum steady anode current, and the superiority of the secondary-emission pentode in this respect is shown by the values of g_m/I_a in the table on this page.

Tubes Compared on Basis of Overload and Distributed-Amplifier Requirements

Tube type	*Mutal Conductance* g_m	*Anode current* I_a	$\frac{g_m}{I_a}$	*Cold capacity* C_g	*Estimated capacity in amplifier* C_g'	$\frac{g_m}{C_g'}$
6AK5	5	7.5	0.66	4.3	7.5	0.67
CV138	7.5	10	0.75	7.6	11.5	0.65
VX5038	19	15	1.27	7.5	11.4	1.67

Secondary-emission tubes. The use of secondary-emission tubes in wide-band amplifiers is increasing. These tubes should give good results in distributed-line amplifiers.

One amplifier with a gain of 60 db has been made by Borg (*2*). This amplifier uses the VX5038 tube. This tube is a pentode with a single stage of secondary emission multiplication; it is constructed on a miniature nine-pin glass base. The amplifier has a single tube per stage, and a bandwidth of 150 Mc is achieved using 20 tubes.

The relative advantages of the VX5038 and the 6AK5 for use in distributed amplifiers are shown in the table on this page. The ratio g_m/C_g' has been taken as a practical figure of merit for the AERE distributed-amplifier designs, since in these amplifiers additional capacity is added to the anodes of tubes to make the anode line impedance equal to the grid line impedance and so facilitate the interstage coupling. These figures show that for a given total amplifier gain, considerably fewer VX5038 than 6AK5 tubes will be needed, with a reduction of amplifier delay time. The grid input resistance of the VX5038 tube is considerably lower than the 6AK5 tube, but since fewer VX5038 tubes are needed, the net attenuation effect of this grid resistance is somewhat less than for the 6AK5 tube.

Fast Oscilloscopes

For nuclear physics applications it is usually necessary to display single voltage pulses. The most useful type of instrument for this is a film recording oscilloscope. Such an oscilloscope can display on a single time base, and auto-

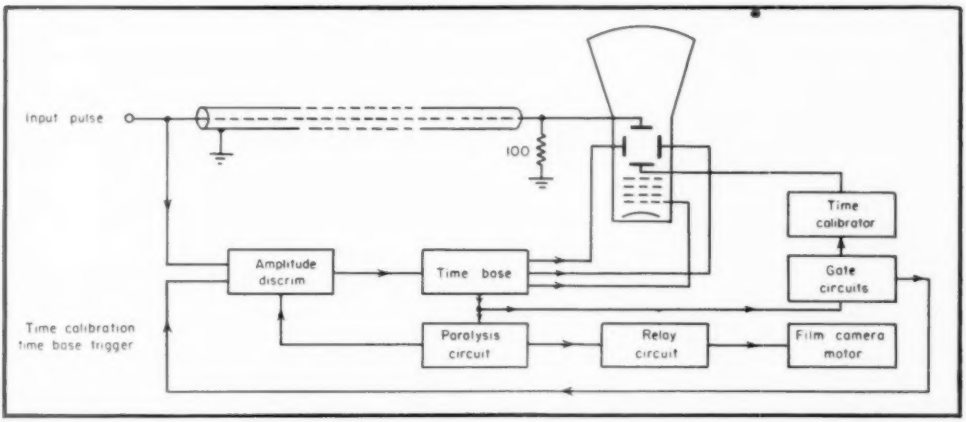

FIG. 6. Block diagram of film recording oscilloscope

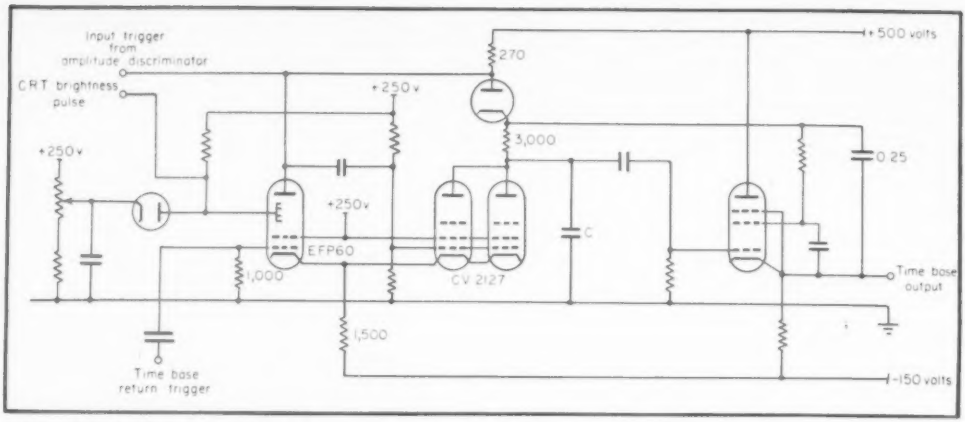

FIG. 7. Simplified fast time-base circuit

matically record on film, a single pulse.

The instrument designed at AERE is shown in Fig. 6.

The cathode-ray tube used in such an oscilloscope must have a very small spot size to obtain a high deflection sensitivity, (expressed in terms of deflection volts per spot-width deflection), but the spot brightness must also be sufficient to give an adequate film record with the fastest time base. The cathode-ray tube used in the AERE instrument has a deflection sensitivity of the order of 3 volts per spot-width deflection when used with a time base duration of 0.1 μsec. This tube uses a single post-accelerator anode and gives a good record on 16-mm film of a single 0.1-μsec time base.

The delay time between application of a small trigger pulse to the oscilloscope circuit and the time when the cathode-ray tube trace attains normal brilliance and sweep velocity must be kept to a minimum for this type of oscilloscope. This delay time is about 25 mμsec for the AERE oscilloscope.

Time base. The basic circuit diagram of the linear time base used in the fast oscilloscope is shown in Fig. 7. The shortest time-base duration with this circuit is 0.1 μsec with an amplitude of 300 volts. This is paraphased by an additional tube, giving a total time-base amplitude of 600 volts.

This circuit is an extension of a normal type of linear time base and has been chosen because it is linear, stable, and simple to switch to a range of time-base durations. The circuit also has a low output impedance, but it is not very suitable for time-base durations of less than 0.1 μsec.

The EFP60 tube and the two CV-2127 paralleled tubes form a cathode-coupled flip-flop circuit that is triggered by the output pulse from an amplitude discriminator which precedes the circuit. The resultant rise of anode voltage of the CV2127 tubes is passed through a cathode follower and used as the time-base deflection waveform. The cathode follower also provides negative feedback to linearize the waveform. The positive pulse obtained from the dynode of the EFP60 tube is stabilized in amplitude by the clipping diode and then applied to the grid of the cathode-ray tube as a brightness waveform. The driving current available from the dynode during this brightness pulse is nearly 300 ma, giving a pulse rise time of the order of 10 mμsec. The EFP60 stage is triggered back to normal and the time base voltage returned to zero by an auxiliary EFP60 trigger circuit (not shown in the figure) which is triggered when the time-base amplitude reaches 300 volts.

Calibration pulse generator. The oscilloscope described above has, in addition to the normal time base, an auxiliary time base for the display of time calibration pulses. The circuit for producing these pulses is shown in Fig. 8. The secondary-emission tube functions well as an oscillator up 100 Mc and gives short voltage pulses across the anode resistance. These are passed through the series germanium diode and used as time calibration pulses. The germanium diode removes any small oscillator waveform present between calibration pulses.

The AERE oscilloscope employs a calibrator of this form with frequencies variable between 1 and 50 Mc. The oscillator is normally biased off on its grid and then switched on by a negative pulse applied to the cathode when calibration pulses are needed.

Oscilloscopes for regular pulse display. These oscilloscopes, in conjunction with regular recurrent pulse generators, can be used in the design of fast circuits.

A fast oscilloscope of this nature has been developed by McQueen (*3*). This oscilloscope has a fastest time base duration of 0.05 μsec. The signal-plate-deflection amplifiers have an effective bandwidth in excess of 300 Mc/sec and sufficient gain to give full deflection of the cathode-ray tube with a 0.5-volt input pulse.

This oscilloscope uses a pulse sampling technique as follows. Each part of the voltage waveform to be displayed is gated in turn (on successive recurrences) by a 1-mμsec pulse, this pulse gradually scanning through the regular waveform to be measured. The mean amplitude of the input waveform is then measured during this gating pulse, and after suitable amplification by low-frequency amplifiers, a voltage proportional to this mean amplitude is obtained. This voltage is used as the vertical plate deflection on the display cathode-ray tube while the horizontal plate deflection is made proportional to the time displacement

of the 1-mμsec gating pulse from a reference pulse which is locked to the input waveform.

If the time displacement of the gating pulse from the reference pulse is slowly increased in a linear manner over a given time range, the horizontal deflection of the cathode-ray-tube beam will be in proportion and so give a linear time base. The vertical deflection will be proportional to the mean amplitude of the input waveform at the gating-pulse instant. Thus a display of the input waveform is produced on the cathode-ray tube at a reduced recurrence frequency.

The mixing stage of this instrument, where the input waveform is gated by the scanning pulse, is shown in Fig. 9. This stage takes the form of a probe and so can be mounted close to the waveform to be inspected.

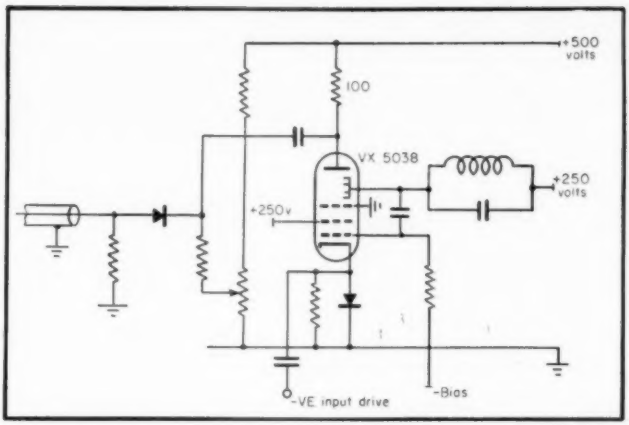

FIG. 8. Pulse time calibrator circuit

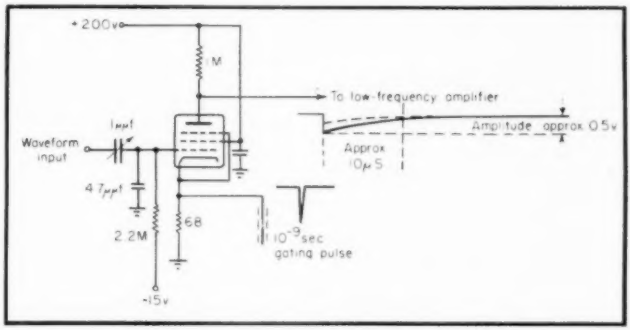

FIG. 9. Simplified diagram of probe-unit input stage

Fast Coincidence Units

In any given experiment using a fast coincidence unit, there are usually three fundamental requirements.

1. The unit shall give the shortest possible coincidence resolving time.

2. The unit shall give the maximum ratio of true to random coincidence counting rate.

3. The random coincidence counting rate must be capable of measurement or calculation.

Some or all of these requirements may have to be met by the coincidence unit. In a large number of experiments the ratio of the true to random coincidence counting rate may also be increased by reducing the strength of the source being used, at the expense of increased experimental time.

To satisfy the second requirement, the coincidence resolving time in the unit should be capable of variation so that, starting from a maximum, it may be reduced until the true coincidence rate begins to fall, showing that some true coincidences are being lost due to time variations introduced by the scintillation counter and the following circuits. If a shorter coincidence resolving time than this limiting value is used, the true coincidence rate will be markedly reduced and will become very dependent on the exact value of coincidence resolving time.

To satisfy the third requirement, the random coincidence counting rate should be measured simultaneously, if possible, with the measurement of true plus random counting rate. Alternatively, the coincidence resolving time may be measured together with the two input counting rates and the random coincidence rate calculated.

The AERE fast coincidence unit employs the now familiar technique of pulse shaping and limiting the outputs from the two scintillation counters. These pulses are then added together; when they are coincident, the resultant double-amplitude pulse is discriminated from the single-amplitude noncoincident pulses by a biased germanium crystal. The output from this crystal is then suitably amplified.

Recent work on this circuit has been concentrated on improving the stability of the coincidence resolving time, and investigating methods for the measurement of the random coincident rate at the same time as the true plus random coincident counting rate. If EMI 5311 type of photomultipliers are used with this circuit, the minimum value of coincidence resolving time before some true coincidences are lost is about 10 mμsec using a stilbene phosphor in the scintillation counter.

Future Trends

The general use of the secondary-emission type of pentode in all fast circuit designs during recent months has resulted in substantially increased operating speeds.

Any substantial reduction of fast coincidence unit resolving times will be largely dependent on the reduction of the transit time variations of photomultipliers, while the design of faster oscilloscopes will be dependent on improvements in cathode-ray tubes.

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Pulse Amplitude Analyzers for Spectrometry

Pulse-height analysis is commonly accomplished by dividing the voltage-amplitude range available from a linear amplifier into increments or windows and determining counting rate in a number of them. Here's what to consider in designing an analyzer

By G. G. KELLEY
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THE STATISTICAL SPREAD of a monoenergetic peak produced by a scintillation counter is roughly proportional to the square root of the energy of the peak. Thus it would seem that, for the analyzer to add a constant, perhaps negligible, amount to the smearing of a spectrum, its window width should be made proportional to the square root of pulse amplitude. Such a procedure is inconvenient, however, and constant width windows usually are used in practice.

It can be shown that, if an analyzer allots at least three, preferably four or more, window widths to a peak between points of half counting rate, it will have little effect upon resolution. Equating the width of n channels to the width of a peak, we obtain

$$n\Delta E = k\sqrt{E} \quad \text{or} \quad n = (k\sqrt{E})/\Delta E$$

where n is the number of channels per peak, E is the position of a peak in some unit proportional to the energy of incident radiation, ΔE is the width of a channel in the same unit, and k is the width of a peak at unit E.

At the present state of the art, a value of 0.07 $Mev^{1/2}$ for the factor k is considered good resolution using NaI(Tl) crystals. Should n be greater than or equal to three, the expression may be used to indicate the value of E (E_{min}) below which a particular window width contributes increasingly to smearing, or it may be used to determine the value of E (E_{max}) above which it is impossible to allot three or more channels to a peak when a channel is a fixed portion of the available voltage spectrum.

$$E_{min} = \left(\frac{n\Delta E}{k}\right)^2 = 1{,}840(\Delta E)^2$$

$$E_{max} = \left(\frac{kN}{n}\right)^2 = 5.4 \times 10^{-4}N^2$$

when the energies are expressed in Mev, $k = 0.07$, $n = 3$, and N is the maximum number of channels into which a spectrum may be divided. It is common practice to divide a spectrum into about 100 channels ($N = 100$), in which case $E_{max} = 5.4$ Mev when $k = 0.07$ at about the upper limit of interest in present high resolution work.

The scintillation counter is not useful in the region below about 20 kev because of poor resolution and other considerations. With $E_{min} = 0.02$, $\Delta E = 0.001$ and 100 channels span the region from 0 to 100 kev. Often it is not possible to adjust the amplifier gain arbitrarily to control the value of ΔE because of amplifier overload limitations. With the amplifiers available at present, a high counting rate of pulses which overload heavily will cause distortion of the portion of the spectrum being observed. Thus an analyzer should be capable of operation down to signal levels of a few window widths above zero signal.

Design for High Speed

Many analyzers have been built to handle long slow pulses at correspondingly low counting rate. Once the nature of the pitfalls that can be encountered are understood, the design of such a device is easy. There are many applications where speed is not important and a slow analyzer is perfectly adequate. Such is not the case, however, in many of the experiments performed in scintillation spectrometry.

Often the pace of the measurement is determined by the maximum counting rate that the equipment will handle, and a factor of 10 in speed may

mean a saving of many hours a week on ordinary experiments involving spectrum analysis.

It is for coincidence spectrometry, however, that high speed is vitally important. Often as few as one count in 100 is recorded by the analyzer. When one considers that of the order of 200,000 counts are required to obtain a spectrum of good statistical accuracy, it is easy to see that if an analyzer can tolerate no more than 1,000 total counts per second, or 10 counts actually recorded, 20,000 seconds or about 55 hours will be required. The inevitable existence of long-term drift in the equipment makes such a long run of doubtful accuracy. It is highly desirable that any single run may be made during the course of one working day.

For this reason, it is the opinion at our laboratory that an analyzer should be capable of operating at counting rates of the order of 10,000 to 20,000 per second. At such speeds, resolving times should be small, of the order of 5 μsec or less, and pulse widths should be in the 1 μsec region.

We have been using 1-μsec delay-line differentiation, which allows the light from the phosphor to integrate for 1 μsec, at which time the pulse is returned to zero along a path which is the negative of the rise. The use of such short pulses makes the design of several of the components of an analyzer quite difficult.

The maximum output readily obtainable from an amplifier at the pulse speeds considered is of the order of 80 to 100 volts. Division of this range into 100 windows makes the width of one channel, at the input to the analyzer, one volt or less. Such channel width is insufficient from the standpoint of stability, since the position of a channel edge cannot be maintained to better than 20 mv over a period of days, and an accuracy of better than 2% is desirable in channel width. Therefore, 3 volts is about the minimum channel width usable, and then additional amplification is required.

The use of a window amplifier is common practice at Oak Ridge,* although it introduces problems of its own. This device is a biased amplifier that can be set to amplify any portion of the spectrum, while overloading gracefully on signals exceeding this portion.

Discrimination

The process of discrimination is common to all analyzers of the type under discussion. This is the process of determining whether or not a pulse has exceeded a certain voltage level. The usual analyzer produces an output in a channel when the level marking the bottom of the channel has been exceeded but the level at the top has not.

The word *discriminator* is not easy to define because discrimination may involve a large portion of the circuit in a rather complex manner, with the burden of decision resting ultimately upon the first stage of the scaler associated with a channel. What is usually meant by the word is a biased amplifier with positive feedback, which transfers from one state of stable equilibrium to another when the discrimination level is exceeded. It is not a "yes" or "no" device, because there is an unavoidable voltage interval whose magnitude depends upon pulse and discriminator speed, in which pulses of intermediate size are produced. It is in this region that the circuitry following the discriminator is involved in the discrimination process.

Let us consider a voltage level and an interval above this level corresponding to a certain percentage of channel width, as illustrated in Fig. 1. This interval may be, for example, 50 mv referred to the output of the linear amplifier. Of a 5-volt pulse, 1% will appear in this region when the level is such that the top of the pulse is at the top of the interval. Only 0.1% of a 50-volt pulse will occupy this interval, however, when the level is changed suitably. It may be seen, therefore, that, since to a first approximation a certain area in, say, volt-seconds, is needed above this line to enter the channel, if the 5-volt pulse just enters, the 50-volt pulse will not.

How much the pulse amplitude must be increased depends upon the shape of the input signal. Thus an error is produced which makes the position of a window higher than expected. Since the speed of the signal seen by the discriminator at the top of the window is slightly greater still, it produces an error in width also. Discriminators should be fast enough that the error in signal position is not greater than 1 to 2% at maximum signal. It is apparent that the error in window width generally will not exceed the position error.

For signals of the type described, tubes of an exceedingly high figure of merit are required if the error is to be held to this amount. In our laboratory, we have been using type 404A tubes and wide-band circuit techniques with satisfactory results. Tubes such as the 6AK5 are used where this standard of performance need not be met.

Discriminator performance with regard to speed may be evaluated through the use of a pulse generator producing a pulse with a fast rise and an extremely flat top. The time required for the discriminator output to reach, say, 0.9 of its maximum value after the beginning of the test signal can be determined as a function of the amount by which the test pulse amplitude exceeds the level of infinite delay.

Beam Deflection

A beam deflection tube is sometimes used to precede the discriminators. It may be seen that such a device may be

* J. Francis, P. Bell, J. Gundlach, *Rev. Sci. Instr.* **22**, 133 (1951); G. Kelley, A multi-channel pulse sorter, ORNL-714, (April, 1950); G. Kelley, Multi-channel analyzer, ORNL-796 (July, 1950).

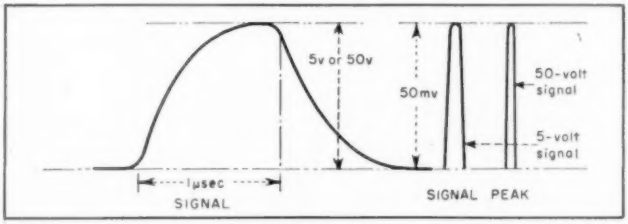


FIG. 1. Variation of pulse speed with change of amplifier bias

thought of as a special kind of amplifier. By the amount that its gain advantage overcomes its instability, it improves over-all stability by making a variation in discrimination level a smaller percentage of channel width. It has the added property that it provides an upper channel boundary, eliminating the need for anticoincidence arrangements.

The gain band width product of a beam deflection tube is proportional to beam current and to the number of spot diameters through which the beam is deflected per volt of signal. If the beam current is made greater than a value of the order of hundreds of microamperes, the spot size is a rapid function of current, and the gain is decreased. The band width of the collection circuit must be in the region of a few hundredths μsec. With presently achievable values of spot diameter per volt, the gain of a beam deflection tube is low, and improvement of performance through its use is doubtful. Whether or not it simplifies circuitry is a matter of argument.

Pulse Length

In the Oak Ridge National Laboratory 10-channel analyzer, and in the new 20-channel analyzer just completed, the requirement of high speed has been transferred from the discriminators to a pulse lengthener. Such a procedure is advantageous in multi-channel equipment since only one pulse lengthener is required and relatively slow simple discriminators may be used. The 20-channel analyzer uses here, for example, type 12AT7 dual triodes.

Pulse lengthening is achieved generally by causing the signal to charge a storage capacity through a diode. When the signal ends, the back resistance of the diode prevents the voltage across the capacitor from decreasing rapidly. While the signal is rising, a voltage drop, of such an amount that the capacity is charged at about the rate of signal rise, must appear across the diode. This drop need not be large, even for very fast signals, if the storage capacity is small, because a few volts of drop across any good diode produces a relatively large current. The region of interest, therefore, with regard to speed is the top one or two volts of the pulse amplitude.

As the rate of change of input signal falls to zero, the drop across the diode will decrease, but exact equilibrium can never be reached. The diode current will not reverse until after the input signal has fallen an amount which depends on the rate of change of signal in this region, the size of the storage capacitor, and the amount of diode current that flows as a function of the remaining drop across it.

If the resistance of a diode is quite high in the region of zero volts, it is seen that, since the drop across it is proportional to the log of current until this resistance makes itself felt, the voltage may differ from equilibrium by a relatively large amount at a low rate of approach.

Thus it appears that high back resistance and correspondingly good lengthening is roughly incompatible with fast response. We have been using germanium diodes and an artifice to achieve both good lengthening and fast response. The 20-channel analyzer uses two diodes in series, with the junction between them held up by a third diode connected through a cathode follower of high gain to the storage capacitor (see Fig. 2). In this way, the back voltage across the output diode is prevented from exceeding about 1.5 volts, at which voltage the back current may be held to $< 0.5\,\mu a$.

Band Width

The window amplifier must be gain-stabilized, and it must be a wide-band device since a nonlinear operation is performed upon the signal at its input.

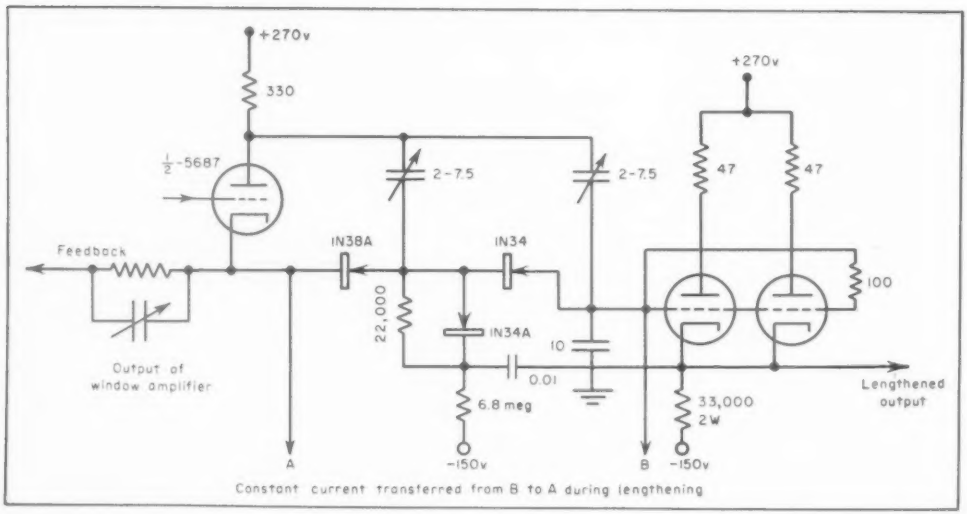


FIG. 2. Pulse-lengthening circuit used in the 20-channel analyzer

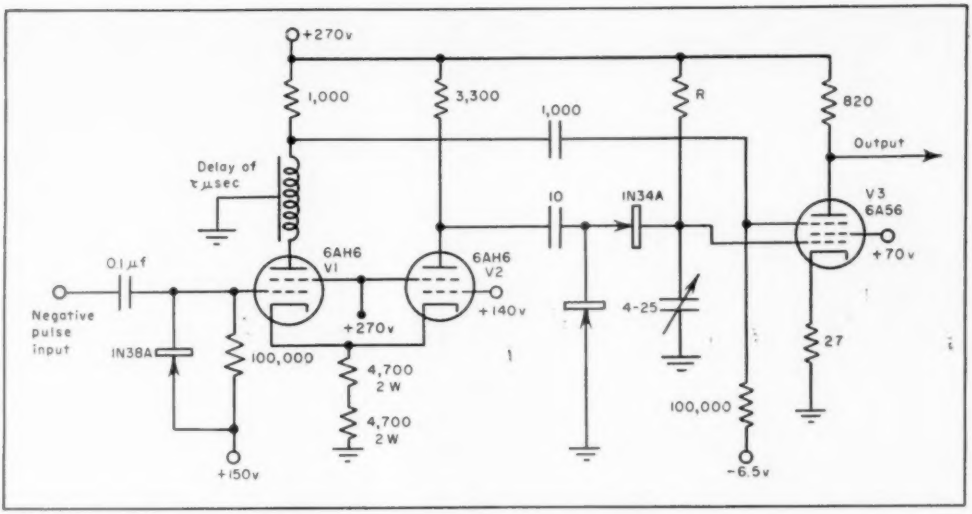


FIG. 3. Pulse-inspector circuit used in 20-channel analyzer

Band width does not affect signal linearity (except for pile-up effects) only in those portions of the circuit which handle signals whose amplitudes are proportional to the input signal amplitude. When, for example, the top 5% of a signal is being amplified, the signal speed in the window amplifier is quite different from the speed when the bias is reduced and all of a small signal is passed. If the band width is not adequate, the gain for fast signals will differ from that for slow signals, with a corresponding change in window width.

Type 404A tubes have been found necessary in this device, although there is some speculation that, by squeezing hard, more conventional tubes may be made to do the job. Another line of approach would be to abandon the window amplifier and concentrate effort on increasing the voltage range from the linear amplifier, but this would require the pulse lengthener, if used, and the discriminators to operate over an inconveniently large voltage range.

Pulse Spacing

The design of an analyzer must be such that the random nature of pulses from a source does not produce serious error. Pulse spacing must have no effect upon an analyzer worse than the failure to record one or both of a pair of closely spaced pulses. That a defect resulting in spurious recording of pulses need not be great to be serious is due to the fact that the true counting rate in a channel may be very small in the presence of a very high counting rate of larger pulses.

Most multi-channel analyzers gate the signal channel "off" during the analysis of a pulse to prevent such an error, but this procedure also results in errors unless there is provision to assure that restoration of the signal channel to sensitivity is not made during the occurrence of a succeeding pulse. Gating is to be avoided if possible.

For the 20-channel analyzer, a circuit has been devised that makes gating unnecessary. This circuit, which we call an inspector circuit, takes as its input a negative pulse of constant amplitude from the linear amplifier marking the time of beginning of each signal. The pulses are passed through the circuit (delayed a suitable amount) only if the pulse is not preceded or succeeded by another pulse within the interval of delay. A form of the device is shown in Fig. 3.

Tubes *V1* and *V2* shape the input pulse. They provide a positive pulse of about 0.4 μsec duration at the plate of *V1* and a negative pulse of the same duration at the plate of *V2*. This latter pulse is coupled through a small capacitor and a diode to a storage capacity and the first grid of *V3*. After the pulse, the voltage on the storage capacitor rises toward zero at a rate determined by R and the storage capacity, adjusted so that the voltage reaches zero at the end of τ μsec. If, however, another signal occurs during this interval, the voltage on the storage capacitor is made more negative by about the same increment as that produced by the first signal and will prevent the voltage from returning to zero until some time later than τ μsec after the second signal.

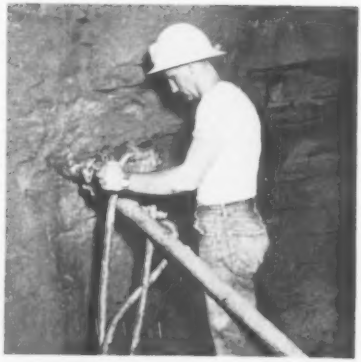
The positive signal from *V1* is delayed τ μsec and applied to the third grid of *V3*, raising the potential of this electrode to a value which causes the tube to conduct if the first grid permits. A signal appears at the plate, therefore, only if an interval τ following the input pulse, and somewhat less than τ preceding it, is free of other pulses.

* * *

This article was presented at the Scintillation Counter Symposium, Washington, D. C., January 30, 1952.

The ideas presented in this paper, to whatever extent they are new, are the result of the experience of all the members of the Physics Division's electronics group and to others at Oak Ridge National Laboratory. P. R. Bell is responsible for much of the philosophy of analyzers. C. G. Goss suggested the form of inspector circuit described.

1 DRIFT MINE tunnels into pocket of uranium ore. This small-scale operation supports independent miner A. C. Rinderle and his family



2 JACKHAMMERS powered by compressed air are standard equipment in larger, company-owned mines

3 CABLECAR rig used to carry ore from mine to truck-loading point is typical mining structure

How Uranium Is Mined

On the Colorado Plateau, which is a kidney-shaped area covering 50,000 square miles at the four adjoining corners of Colorado, Utah, Arizona, and New Mexico, uranium ore is being mined at a rate that places U. S. production second only to that of the Belgian Congo. Both large and small mines contribute to the total. Tiny, rabbit-warren mines run by independent miners supplement the production of extensive, mechanized operations financed by large corporations.

Part of the reason for this diversity is that uranium does not run in veins, but is found in pockets. It does not pay to set up mechanized equipment to clean out a small pocket, but a man can support his family by mining one small pocket and then another. However, even though uranium metal is 45 times as valuable as gold, the miners find that they get less per ton for the low-grade carnotite ore found on the Plateau, since the yield per ton of ore is higher for gold.

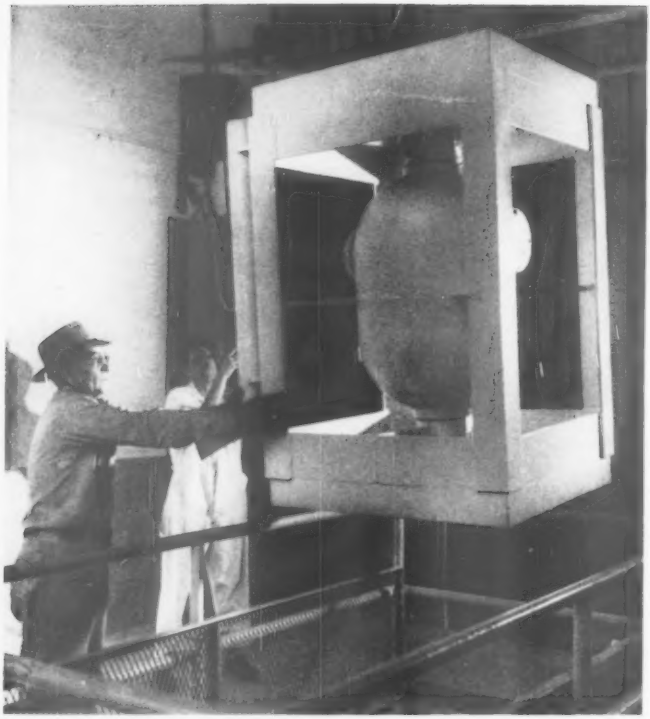
Mining is made more difficult because there are few good roads. Rough roads, where there are roads, are blasted out of the rock and cleared through the sagebrush. Grades run as high as 30%. Over these trails, trucking concerns carry the ore to the refining mills. Once again, equipment is diverse. The big haulers use 6-wheel, 21-ton trucks; the smaller operators, almost anything.

At the refining mill, the ore is ground up and processed. Assays determine the uranium content, on which the miners' pay is based.

4 GIANT TRUCKS powered by 300-hp diesels haul 21 tons of ore 214 miles to the mills

5 REFINING MILL at Uravan, Colo., was established by U. S. Vanadium Corp. in 1940. It formerly produced coloring agent for ceramics

6 URANIUM, refined from ore, is a black sticky substance. Here it is being shoveled into a dryer that transforms it into a powder. This natural uranium is collected in barrels and shipped to the atomic energy establishments for further processing



ONE THOUSAND curies of cobalt-60, largest radioactive source ever produced in the United States for treatment of cancer, getting started recently on trip from Oak Ridge to the Los Alamos Tumor Institute. To be used in teletherapy unit, source contains radiation equivalent of $25,000,000 of radium, was bought for less than $10,000. Carrier, weighing over 4,000 lb, included 3,000-lb, 8-in.-thick, lead container to shield the cobalt which is in the form of six small rods that total ½ lb in weight
Wide World Photo

New Developments in Teletherapy

As long as radium was the only source, teletherapy machines were limited to the rigid restriction of one curie per gram. Now radioisotopes have thrown the field open to innumerable possibilities. What this means to the cancer therapist and machine designer is summed up below

By MARSHALL BRUCER
Chairman, Medical Division
Oak Ridge Institute of Nuclear Studies
Oak Ridge, Tennessee

TELETHERAPY UNITS incorporating kilocurie sources have provided an active field for development that is currently showing achievements in combination with limitations.

Availability of the right radioisotope is the first and foremost limitation. Production and manufacturing problems are not simple. To some extent, many of them can be solved specifically to fit the therapist's needs—if we know what the therapist wants.

Radiophysicist, therapist, distributor, manufacturer, and machine designer met recently at the AAAS Symposium on Cancer Therapy with Radioisotopes to discuss not only problems but also new developments in teletherapy.

Some of their ideas and the papers they presented are abstracted on the following pages.

(Only the afternoon session of the symposium dealt with the subject of teletherapy. Morning and evening sessions were devoted to papers on "Internally Administered Isotopes for

Cancer Therapy," as reported in an article by this author in the March NUCLEONICS, pages 46–51.)

The Radiotherapist's Needs in Teletherapy

By Robert Robbins
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The therapist will ultimately decide which design of teletherapy machine is best, but since this decision will be based on the results in treating patients, his final decision will follow, not precede, the work of the designer. To allow the widest latitude in developing new machines, he should make only the most general recommendations.

Experience with the million-volt X-ray machines leads us to expect several important advantages from the radioisotopes available for teletherapy machines: Better skin tolerance, more accurate tumor dosage, less absorption in bone, better depth dose, increased flexibility, and lower cost.

The dose rate demanded by the therapist will determine the source size and, hence, the dimensions of the machine. If radiation is delivered too slowly, the treatment time increases and patient-handling problems become impractical. Very fast delivery of the dose is unnecessary, and probably will decrease accuracy of dosage. A dose rate less than 10 r/min is probably undesirable. A rate over 100 r/min is probably unnecessary and wasteful.

The source-skin distance is of little importance except in its effect on depth dose. Naturally the therapist needs as favorable a depth dose as possible. Minimum requirements should be those now found in standard X-ray equipment. Any improvement is a desirable gain, but must be balanced against the disadvantages of increased weight, size, and cost which come with increased source-skin distance.

The machine should be designed to take advantage of present knowledge on portal sizes, and methods of application but should not be bound to current prejudices. Portals less than 3×3 cm are seldom used. Portals greater than 15×15 cm are improper, except in very special circumstances.

The question of allowable penumbra is a problem that needs careful specification. In rotation therapy, it must be minimized; in single portal therapy, it may be advantageous. With multi-

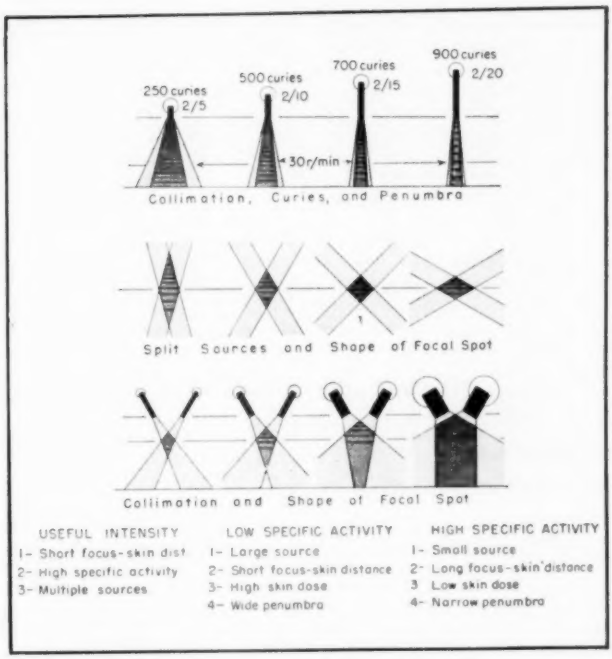

FIG. 1. Factors for consideration in estimating multicurie sources

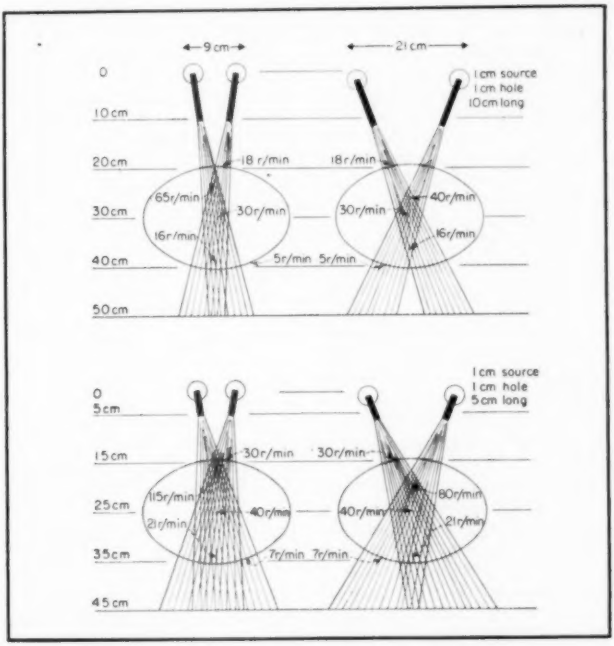

FIG. 2. Effect of beams from four split Cs^{137} sources totaling 500 curies

ple portals, deliberate and variable penumbra patterns may increase the usefulness of the machine.

The therapist should seek maximum protection with gamma-emitting devices. From the standpoint of the operator, a teletherapy unit in the "off" position should certainly deliver less than the established maximum permissible dose of 0.3 r/week.

Probably of greatest importance to the therapist are the needs for flexibility, maneuverability and accuracy. In the history of radiation therapy, not only physicists but clinicians also have made major contributions. Radiotherapists should be encouraged to apply their empirical methods to the study of the newer teletherapy units.

The Radiophysicist's Requirements in Teletherapy

By C. B. Braestrup
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New York, New York

Although it is impossible to state rules and regulations for designing teletherapy units made from incompletely known isotopes, some general recommendation can be made from our previous experiences with X-ray therapy. The main design factors are:

1. Energy of radiation. Because depth dose increases with increasing energy, supervoltage has a distinct advantage in treating deep-seated lesions. Further, absorption in bone compared with soft tissue is relatively less at the higher energies. These advantages have already been established clinically with present 2-Mev X-ray equipment, which delivers a radiation equivalent to that from Co^{60}. With this type of radiation (1.17 +1.33 Mev), the skin tolerance is no longer a restriction in treating deep-seated lesions because maximum ionization occurs about 4 mm below the skin. However, the integral, or volume, dose is still a limiting factor, although to a lesser degree than at lower energies.

A disadvantage to high-energy radiation is the heavy shielding required for the treatment room. For example, a 40-inch concrete barrier is required to reduce the useful beam of a 1,000-curie Co^{60} source to the permissible level of 6.25 mr/hr at a distance of 10 feet; 30 inches would be required for an equivalent amount of Cs^{137} because the energy is lower, 0.66 Mev. Such heavy shielding cannot be easily added to existing buildings. There is, therefore, a need also for sources with still lower energy.

2. Specific activity. The source activity must be high enough to give a practical dose rate, preferably not less than 10 r/min, nor more than 100 r/min. Lower dose rates are impractical in handling patients; higher dose rates give treatment times too short for accurate exposure.

A high specific activity reduces the volume of the source and, therefore, reduces self-absorption and penumbra. Penumbra is usually considered objectionable, yet there are conditions where it is of value. The penumbra has the effect of rounding off the isodose curves at the edges of the field. This is an advantage when irradiating spherical or ovoid lesions through a single port as the isodose curves will follow more closely the contours of the tumor. Furthermore, in cross-fire techniques, the penumbra tends to reduce the high dose at the intersection of the fields outside the tumor. When using small fields, a pronounced penumbra is objectionable, and the source area in any case should not exceed size of the smallest field used.

Increasing the source area improves the depth dose, but it also requires additional shielding.

3. Source-skin distance. Because the percentage depth dose also improves with increased source-skin distance, this factor should be as great as practical. It ought not be less than five times the tumor depth. For this ratio, the divergence of the rays, assuming a point source and no absorption, gives a ratio of tumor dose to skin dose of 0.69. If the source-skin distance is increased to ten times the tumor depth, the ratio becomes 0.83, an improvement of 20%. However, as the source-skin distance is increased, the exit dose becomes greater; the net gain, therefore, is less if opposing fields are used.

A disadvantage to unrestricted increase of source-skin distance is that the treatment time increases as the square of the tumor-source distance; this makes the use of long distances costly. Source-skin distances of 50–70 cm seem to be the practical maximum at present.

4. Single vs multiple sources. A single source offers greater flexibility and a minimum amount of shielding around the source. However, if the specific activity is low, multiple sources may be used to advantage for the simultaneous treatment through several ports. Greater accuracy is obtained with this method, but its clinical usefulness is limited in that the number and orientation of the fields are fixed. The greater shielding requirements of multiple sources make the unit cumbersome and is a distinct disadvantage.

5. Stationary vs rotation therapy. Rotation therapy is merely an extension of multiple-field irradiation, with the axis of rotation passing through the center of the tumor. In roentgen-rotation therapy, the patient is usually rotated and the X-ray tube kept stationary. In teletherapy, it is relatively simple to rotate the source of radiation. This has the advantage that the patient can be treated lying down. With rotation teletherapy, there are the further advantages that set-up time is less than with multiple-field irradiation and operating personnel receive less exposure.

6. Protection of patient and personnel. The stray radiation received by the patient should not be more than 0.1% of the useful beam, except that movable diaphragms may allow 3 to 5% transmission.

A shield approaching a sphere in shape with the source in the approximate center when the machine is in the "off" position provides maximum protection for a given weight.

Beam control should be accomplished by moving the relatively light source rather than a heavy shutter. By mounting the source on a turntable rotating in a plane at right angles to the useful beam, the radiation leakage is very much reduced.

Plans and possibilities. Isotope teletherapy permits the use of new and more effective methods of irradiation not possible with conventional roentgen therapy equipment. Such methods should be fully explored rather than just duplicating existing roentgen therapy techniques.

As suitable isotopes become more readily available, it may be possible to construct irradiators for specific purposes. For instance, cancer of the neck might be effectively treated with a unit irradiating simultaneously through two opposing fields.

Objections to a short half-life of Co^{60} may be partially overcome by a system such as planned for the New York City hospitals. The Co^{60} ir-

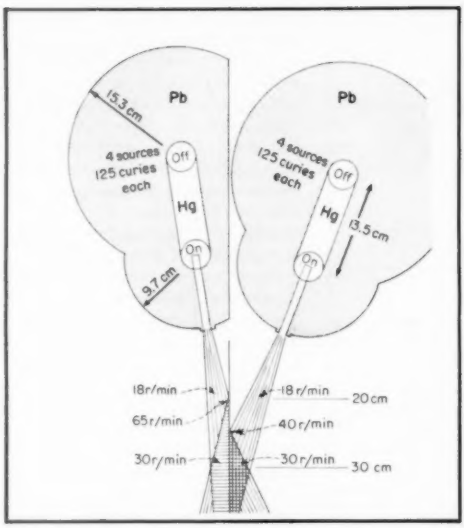

FIG. 3. Minimum protection from 500 curies of Cs^{137} split into four sources

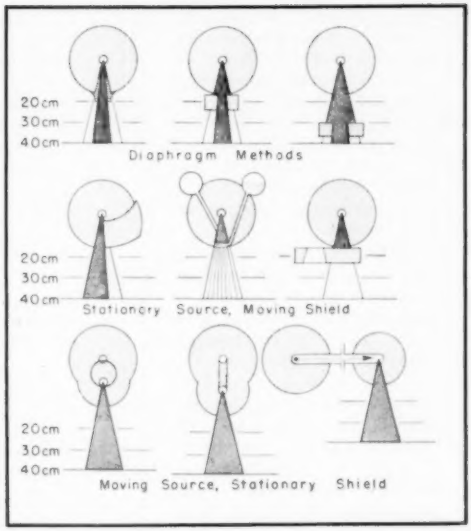

FIG. 4. Variations of three methods for shielding a 500-curie Cs^{137} source

radiator will first be installed in our busiest radiotherapy department and used there until the activity is down to 75%; the irradiator, including shield, will then be transferred to a less busy hospital, while the first institution will receive a new cobalt unit. This chain of users may eventually be extended to five hospitals; thereby increasing the useful life of the irradiator to about two half-lives and at the same time maintaining the dose rate within 25% at any given hospital.

Availability of Teletherapy Sources

By James R. Mason
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At present, only two large teletherapy sources of cobalt-60 have been put into use. Both of these were produced in the Canadian reactor at Chalk River and are being used in Canada. Approximately 10 sources of 1,000 to 1,500-curie strength have been ordered by United States radiologists, and some of these are in production. Since the Canadian reactor at Chalk River has a higher neutron density or flux and therefore a faster isotope production rate than any reactor available for radioisotope production in the United States, the first sources are being produced in Canada.

We have been actively working on the teletherapy source problem in the United States and will have high-activity sources available for delivery in the not-too-distant future. There is now some Co^{60} at Oak Ridge with a specific activity of up to 8 curies per gram from which one moderately high-level source has been made and several more similar sources could be made. This source has a gamma-ray output of 15 r/min at 50 cm.

Although not readily available to all potential customers at the moment, much progress is being made with kilocurie sources, and we believe that a great number of units can be produced within the next few years.

Some Proposed Teletherapy Units

By Marshall Brucer
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Oak Ridge, Tennessee

From a review of the current status of the production of multicurie sources of gamma radiation, there appear to be only six practical isotopes with characteristics suitable for teletherapy units. Europium-152-154, iridium-192, cobalt-60, and tantalum-182 sources can be produced efficiently in a nuclear reactor with thermal neutrons. Cesium-137 and cerium-144 can be produced by separation from mixed fission products.

At the present time Cs^{137} appears to be the most economical and desirable isotope for teletherapy by a considerable margin. Because it will probably be generally available in large volume within the next few years, it has been selected for detailed study. If and when a high-flux nuclear reactor becomes available to the medical profession, it may be possible to produce Eu as economically as Cs. Co^{60} is probably more desirable than Eu because of its monochromatic radiation, but it will undoubtedly be more costly to produce.

A Cs^{137} source could be used in a teletherapy unit in two basic ways: as a single large source collimated to produce a single beam, or as multiple small sources collimated to converge at the lesion.

In Fig. 1, the combined effects of collimation, specific activity, and penumbra are shown. Let us assume for the present that 30 r/min is an adequate treatment intensity. This can be achieved with as little as 250 curies collimated through an aperture 2.5 times deeper than the diameter of

the source. However, the penumbra would be very wide and the shielding material would have to be denser than lead. If a collimating aperture 10 times the diameter of the source is used, the penumbra is probably narrower than necessary. The source is farther removed from skin than necessary to minimize the attenuation due to the inverse square law, and this may be a wasteful use of Cs^{137}. For the purpose of investigating various design factors, it is arbitrarily assumed that a rather wide penumbra can be tolerated. A 500-curie source can be shielded by lead to produce a reasonably sharp beam of radiation with an intensity of about 30 r/min at 30 cm.

If the 500 curies are split into four sources with converging beams, two other factors enter into the design. Both the angle of separation and the effective collimation of each source change the shape of the area of most intense radiation. Thus, all design problems ultimately are related to one major consideration, the size and intensity of the source.

The limits of sizes of the sources to be made available will be set by the problems of manufacture and will not be the ideal "point sources," or anywhere near them. Certain factors become apparent to the designer. To produce an adequate treatment intensity, a high specific activity gives the greatest freedom in design. As the specific activity is lowered, the treatment distance must be shortened. At very short treatment distances, the skin dose is unacceptably higher than the dose in depth because of the inverse square effect, and multiple sources or multiple portals must be used.

If only low-specific-activity sources are available, the source must be large; and the machine must be built with a very short source-skin distance. There will be a high skin dose and a wide penumbra. Such sources will not be much competition to radium except in price. The radium teletherapy units have been very useful and comparable machines can be made very easily and at a low cost with Cs^{137}, but it is difficult to justify spending large sums of money on such a poor set of compromises when so much better results can be achieved with the specific activities soon to be available.

If the source is split into four pieces and focussed as shown in Fig. 2, the pattern of the focal area changes

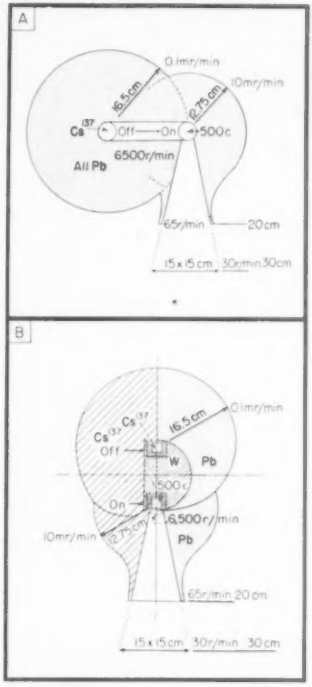

FIG. 5. Two adaptations of design in which source is mounted on internally rotating wheel. Minimum protection from 500-curie Cs^{137} source for each arrangement is shown

with the angle of separation. A very narrow angle gives an unacceptably narrow cone of radiation with a hot spot at the point closest to the sources. In order to approach a desirable focus shape, the beams must be widely separated—so wide that, in effect, these beams are best produced by multiple portals rather than by one machine with split sources. In Fig. 3 it can be seen that beyond a certain angle of separation the shielding becomes effectively four separate machines rather than one machine with four sources.

By decreasing collimation, the pattern can also be modified to produce a beam somewhat more desirable in shape. However, the volume of tissue receiving appreciable radiation is increased significantly. With such a design, to get a desirable intensity, the therapist will be allowed no choice but to irradiate indiscriminately whole sections of the body.

For this reason, the use of multiple sources has been discarded and emphasis has been placed upon the design of a single-beam machine to be used just as supervoltage X-ray equipment functions. The one major advantage is that the size of the equipment allowable with a Cs source gives a flexibility impossible to obtain with the million-volt X-ray machines of the Van de Graaff, or alternating-current, types, or even with the Co^{60} machine.

Figure 4 shows various schemes for shielding a 500-curie source of Cs^{137} in a housing 4 cm in diameter. A lead sphere, 16.5 cm in diameter, surrounds the housing. Metals other than lead could be used to obtain a sphere of smaller diameter, but they would be more expensive.

Two basic methods are available to turn the beam of radiation on and off. To turn it on, the shielding can be moved away from the source, or the source can be moved to the "on" position.

The problem of the moving shield can be solved with liquid mercury or with a solid block of material. In any system with a stationary source and a moving shield, the distance between the source and the skin is automatically increased by the amount of necessary shielding. This increased distance automatically requires a higher specific activity. With a solid block of material, there is always present an additional serious problem of leakage through cracks in the shield. The solution lies in stepped surfaces and close machining tolerances. This results in additional machining costs. Since a movable shield adds to the size of the machine, little room is left for diaphragms, cones, and other applicators. With lower activity sources, the area immediately next to the patient is a critical one both from the standpoint of flexibility and from considerations of the cloud of scattered secondary electrons around the cone.

It appears most reasonable to move the source rather than the shield. This can be done with a separate storage container and treatment head. Both pneumatic and mechanical methods already have been used to move Ra sources into the "on" position. Although the engineering involved in such designs is complicated, such mechanisms have been very efficient in dealing with the very high gamma energies of radium. However, the

660-kv gamma photons of Cs are too easily shielded to demand such an elaborate design.

The source may be moved through a liquid mercury shield, but to date the design requires an additional projection on the top of the machine. The engineering problems of sylphon pressure chambers and of an adequate seal for mercury have been solved on other types of machinery and should not be too difficult to adapt to a teletherapy unit. Every such design, however, takes up space which reduces the flexibility of the machine.

A more serious problem with the Hg shield is in removing all of the Hg from the path of the beam. Small amounts of mercury in this critical location have been shown to be significant in one Ra teletherapy unit and will be even more significant in a Cs unit. Moreover, a pressure of about 100 psi is necessary in one existing machine. Such a pressure demands the use of a thick shell which will act as an unnecessary filter in the beam.

The simplest and most foolproof design seems to be one in which the source is mounted on an internally rotating wheel. This wheel acts as a shield and also serves to turn the source to the "on" position. Only the diaphragming and collimating devices need be in the path of the beam, and the only necessary filtration is that inherent in the source container. By using a spring-loaded return, the machine can be used in any position. There are a minimum of external protuberances and none need be in a forward position. The machining problems are all straightforward and close tolerances are unnecessary. It would appear that such a design has the least possible weight and the smallest size.

Two adaptations of this basic design are shown in Fig. 5. In diagram A, it is shown as modified by Braestrup for rotation therapy. The wheel rotates in a horizontal plane, and the major shielding weight is as close as possible to the plane of rotation around the patient. For the more routine usage, the setup shown in diagram B can be used. It illustrates the minimum dimensions necessary for a very strict definition of required shielding.

If the maximum permissible dose is 0.1 r/min at the surface of the machine in the "off" position, the shielding will be roughly 16.5 cm in radius. If the patient can receive 100 times the maximum permissible dose, the forward cone and collimating device must be a minimum of 12.75 cm in radius. Since tungsten (W) alloy is commercially available in 6-inch disks, it is possible that the entire machine could be shortened somewhat by making the internal rotating wheel more dense than Pb.

Although such a machine with only 500 curies of activity will have a limited usefulness, designs for machines to contain up to 2,000 curies may follow the same pattern and would need only a few centimeters' additional shielding. The first task in implementing this design is to get certain information which will allow accurate engineering.

The linear absorption coefficient for the radiation from Cs^{137} must be measured in Pb, W, Hg, and other materials, for both narrow and broad beams. The self-absorption of Cs^{137} in various Cs salts must be measured to allow an estimate of the most efficient source dimensions. The pattern of scatter through cracks must be mapped out. The electron scatter from surfaces must be measured to allow for intelligent designing of cones and diaphragms. These measurements are now being made at Oak Ridge with a 2-curie sample source and will be published before the Cs^{137} is available for general distribution.

Problems in Manufacture of Fission-Product Therapy Sources

By A. F. Rupp
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The use of certain fission products in teletherapy units appears promising. Considering that fission-product source material for teletherapy work must emit gamma radiation, have a half-life longer than 150 days, and occur in high fission yield, the list of possible fission products is reduced to only two: cesium-137, which has a 33-year half-life and 0.662-Mev gamma radiation from the 2.6-minute barium-137 daughter; and cerium-144, which has a 275-day half-life and 0.135 to 1.25 Mev gamma radiation from the 17.5-minute praseodymium-144 daughter. It is desirable that the fission products be separated with high purity so that an intense source of minimum weight and volume can be fabricated.

The first problem in producing such sources is separation of the fission products and purification without the addition of isotopic carrier so that a product of high specific activity is obtained. Processes for accomplishing this have been developed, but up to now such separations and purifications have not been made on the kilocurie scale required for teletherapy sources. Experience with 100-curie batches of fission products indicates that it is possible to extend existing methods to the production of very large quantities. However, serious problems are encountered at these high radiation levels; one must contend with, for instance, increased complexity of remote-control processing apparatus, the effects of intense radiation on materials, and the necessity for essentially foolproof operational techniques. After preparation of the pure radioactive material, an entirely new set of problems is confronted in drying the material, handling the dry solids, fabricating the internal source, and sealing the finished source.

During the formation of radioactive Cs^{137} by uranium fission, comparable quantities of stable Cs are being produced. In chemically isolating Cs^{137}, the stable Cs is necessarily separated with it, thereby reducing the specific activity of the material which can be obtained. This can be controlled to some extent by the time that the uranium is allowed to remain in the nuclear reactor; however, it is not practical to use such a procedure since the amount of Cs^{137} obtained per unit weight of uranium would be uneconomical. In addition to the stable isotopic diluent, other elements such as Rb and K which have chemical properties very similar to Cs are introduced from impurities in chemical reagents and other sources. There is also a practical limit to which such impurities as Fe, Pb, Ca, Mg, and silica can be removed. Similar problems are encountered in separating Ce^{144}.

Cesium or cerium, to be used in a source, must be prepared in the form of a chemical compound, the radiation stability of which must be carefully considered. For example, nitrates would not be desirable because they decompose under radiation with the evolution of oxygen. The weight added in producing the compound is also an important factor. It is probable that compounds such as car-

bonates, oxides, silicates, or sulfates would be selected.

The thermal stability of these compounds must also be considered, together with such properties as tendency to "creep" during the evaporation, hydroscopicity, water of crystallization, and decrepitation of crystals upon drying. To approach true density of the chemical compound in the finished source, it is necessary to compress the material under high pressure so that its behavior can be considered.

The following table illustrates the marked difference in radioactivity obtainable per unit volume in a long-lived and a relatively short-lived radioisotope.

Calculated Weight and Volume of Cesium-137 and Cerium-144 Kilocurie Sources

	Cs^{137}	Ce^{144}
Gamma radiation (Mev)	0.662	0.135–1.25
Compound	Cs_2SO_4	CeO_2
Weight (gm)	42.7	1.6
Volume (ml)	10.0	0.5

It is evident that although long half-life is convenient and desirable in such sources, some sacrifice must be made to approach a point source of radiation.

The mechanical operations in fabricating such an intensely radioactive source are a major problem. The radioactive material must be pressed into a thin inner container and sealed by soldering. After inspection and testing, the inner source must be sealed within the actual source holder, which may be closed by a suitable cap secured in place by pressfitting or by screw threads, and again sealed by soldering. It will be necessary to store the finished sources, possibly for several months, so that they may be inspected for leakage, swelling, or other signs of deterioration.

The source must be loaded into specially-designed shipping containers constructed so that a safe transfer may be made into the user's teletherapy unit. In some cases, it may be necessary to load the unit at the plant.

The design of a plant for fission-product-source production must also include special features to insure safe operations, since the accidental dispersion of a few milligrams of dried pure fission products of high specific activity would be sufficient to contaminate a large area.

Although many serious problems not foreseen at this time will be encountered and solved in addition to those mentioned, we are confident that it is reasonable to look forward to the availability of kilocurie fission-product sources within the next five years.

Present and Future Problems of Radioisotope Manufacture

By James A. Cox
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Oak Ridge, Tennessee

The major problems connected with manufacture of reactor-produced isotopes include: (1) producing enough to meet the demand, (2) producing them with a high enough specific activity, and (3) producing them with a satisfactorily high purity.

The problems of quantity and specific activity are considerably aggravated by the low neutron flux (10^{12} n/cm^2/sec) available for radioisotope production in the graphite-moderated pile at Oak Ridge National Laboratory. The low neutron flux limits the specific activity and requires the waste of considerable space and reactivity in efforts to make up the deficiency by use of (n,p) reactions. The (n,γ) reactions require much less space and are much less wasteful of neutrons.

Some of the problems of manufacture can best be illustrated by examining the following important radioisotopes: I^{131}, P^{32}, C^{14}, Na^{24}, S^{35}, Ca^{45}, K^{42}, Fe^{59}, Co^{60}, and $Sr^{89,90}$. Of these, I^{131} and $Sr^{89,90}$ are fission products and the main production problems are those of chemical separation.

C^{14} is best produced by a (n,p) reaction on nitrogen.

Na^{24} and K^{42} cannot be made by (n,p) reactions since no $Z+1$ parent exists, and there is no choice except to use the (n,γ) reaction. This results in unsatisfactory specific activity for some applications.

This leaves P^{32}, S^{35}, Ca^{45}, Fe^{59}, and Co^{60}. All can be produced by either (n,γ) or (n,p) reactions. The first two are generally made by (n,p) reactions to meet specific activity requirements. It would be preferable to irradiate phosphorus instead of sulfur to make P^{32} if the neutron flux were high enough to give a specific activity satisfactory for medical use.

Ca^{45} is produced either by (n,γ) reaction on calcium, or by (n,p) reaction on scandium. In this case, the (n,γ) reaction is satisfactory for some applications while others, particularly biological ones, require high specific activity and the (n,p) reaction must be used. This results in low yield and a difficult separation of calcium from highly radioactive scandium.

Fe^{59} is an important radioisotope for many biological experiments which generally require high specific activity. The reverse is true of some industrial applications. A specific activity of 30 mc/lb of iron may be quite satisfactory for an oil company testing engine wear and lubricating oils with radioactive piston rings; it would be entirely unsuitable for medical use. Little success has attended efforts to produce this important radioisotope by a (n,p) reaction on cobalt and it is, consequently, produced by (n,γ) reaction on a stable iron isotope.

Co^{60} is important in industrial radiography and in medical applications where it may be used in many shapes and activities. In both cases high specific activity is essential.

Larger quantities of radioisotopes could be produced with a high-flux reactor. At present, a large number of samples of a few short-lived isotopes must be produced each week (one irradiation per customer) and shipped immediately upon removal from the reactor so that sufficient radioactivity will remain upon arrival. A high flux would permit a single irradiation of each short-lived isotope. Because of the higher specific activity, it would be possible to take time to dissolve the irradiated materials and make as many shipments as desired from the single irradiation.

Thus, most problems concerned with manufacture of radioisotopes hinge upon the availability of a reactor having a high neutron flux to meet increased medical, scientific, and industrial demands both for larger quantities and higher specific activities.

* * *

The Symposium on Cancer Therapy with Radioisotopes, which was held on December 28, 1951, at Philadelphia, Pa., as part of the program of the annual meeting of the American Association for the Advancement of Science, was sponsored by the Oak Ridge Institute of Nuclear Studies and the Isotopes Division of the Atomic Energy Commission. The author wishes to acknowledge the courtesy of the symposium participants in making abstracts of their papers available for presentation here.

Energy Absorption by Externally Irradiated Liquids—I

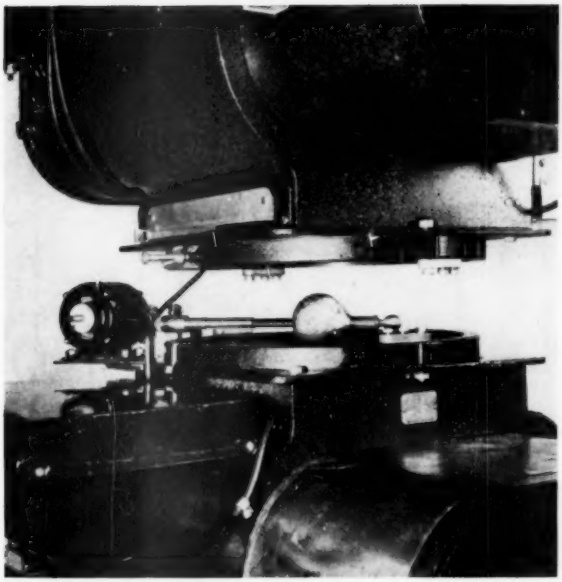

FIG. 1. X-ray source used for bilateral irradiation

Since the direct determination of energy absorption is difficult, it is necessary to convert from ionization-chamber measurements. Two methods for making the conversion are discussed

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IF CERTAIN LIQUIDS and solutions are exposed to high-energy radiation, such as X- or γ-rays, chemical changes ensue which are the result of processes attendant upon the absorption of energy from the incident beam (*1*, *2*, *3*). An estimate of the amount of absorption under various conditions of exposure is necessary in order to refer the chemical data to a common energy unit. When this is done it is possible to compare the relative radiosensitivities of different reactions and to determine if the experimental results are in accord with predictions from current theories. The X-ray source used in this laboratory is shown in Fig. 1.

An experimental determination of the increase in energy content caused by irradiation of a liquid sample would be by far the most direct and satisfactory way of arriving at the desired result, if there were available a convenient and accurate method for measurement of this quantity. However, no very good method exists at present and it is necessary to obtain a figure by conversion from the scale reading of an ionization chamber. This procedure, although the best available, is subject to a considerable uncertainty due, for the most part, to the difficulty in making allowance for the fate of the scattered quanta.

Two methods will be given for making this conversion: the first involves an integration for the average intensity throughout the irradiated volume; the second requires values for the average intensity over planes tangent to the top and bottom surfaces of the sample, and determination of the energy absorption by difference. The actual calculations will be given next month in Part II of this two-part article.

For each calculation it has to be assumed that the once-scattered quanta escape from the sample without contributing to ionization in the liquid. This will not, of course, be true in general but the approximation will become better as the sample becomes smaller and/or the incident radiation becomes more energetic, since under these conditions the average path of

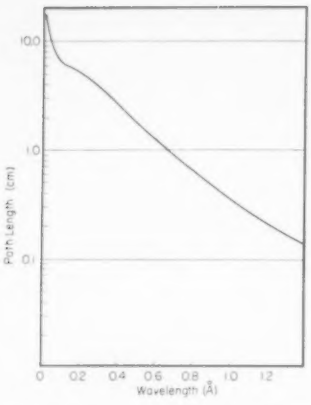

FIG. 2. Average path length of scattered quanta in water as a function of wavelength

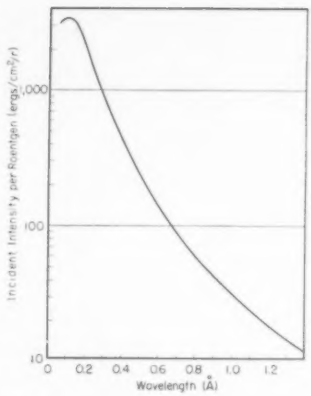

FIG. 3. Amount of incident energy per cm^2 necessary to increase energy content of isolated centimeter cube of air by 0.1083 ergs

the scattered quanta may be considerably greater than the dimensions of the irradiation cell (Fig. 2).

If one starts with a very large sample and decreases the volume steadily, the following three cases may be distinguished:

1. For very large volumes, the once-scattered quanta are almost completely absorbed by a mechanism in which scattering of orders higher than the first is involved.

2. For some intermediate volume, the scattered radiation escapes nearly completely from the sample without being absorbed or rescattered

3. With very small volumes, the scattered radiation behaves as in case 2, but there may be a complication due to the departure from electronic equilibrium at the interface between the liquid and the container

Case 1 is analogous to a problem which has been rather extensively studied by physicists working in the field of radiation therapy (*4–8*). This problem, which has not been completely worked out theoretically, is concerned with the distribution of intensity and wavelength throughout a large mass of tissue under external irradiation by X- or γ-rays. In a practical way the problem has been resolved to some extent by means of isodose contours and depth-dose tables (*9–12*).

Case 2 represents a condition which, at least in principle, can be solved with some accuracy.

Case 3 is related to the electron flux near an interface where there is a discontinuity in density and effective atomic number, and is formally similar to the physical situation which exists in the cavity ionization chamber.

When a suitable thimble chamber is placed at the sample position in the radiation field, a reading is obtained which is proportional to the energy absorbed from the radiation by air. This is used in conjunction with the absorption coefficients for the medium and for air in the estimation of the energy absorbed by the medium. Heterogeneity of the incident beam, absorption and scattering in the container wall, and the distribution of intensity throughout the irradiated volume, as mentioned above, all have an effect on the result and can be allowed for in the calculation.

It is assumed that the thimble chamber used for the measurements has been calibrated against the standard free-air chamber so that it gives a correct reading in roentgens over a wide range of wavelengths. This implies that the reading is referred to a chamber where the photo- and recoil electrons generated in a known air volume are completely utilized in ionization, where there is no wall effect and the scattered quanta do not contribute to the ionization (*13–17*). Under these conditions, the energy absorption per roentgen per cubic centimeter of standard air is 0.1083 ergs if the energy required to produce an ion pair is taken as 32.5 ev; corrections to this value may be made when the air is not under standard conditions (*18, 19*).

It is believed that the commercial thimble ionization chambers now in common use give results in agreement with the free-air chamber down to a quantum energy of about 30 kev, when wall absorption begins to become prominent. For radiation of lower energy, it is necessary to use some other method of measurement such as a very-thin-wall chamber or possibly an improved form of scintillation detector (*20*).

Of course, the amount of radiant flux which is necessary to produce this amount of energy absorption varies considerably with the quantum energy of the incident radiation because of the increase in the absorption coefficients of air with increasing wavelength. This is illustrated in Fig. 3, which shows the amount of incident energy per square centimeter necessary to increase the energy content of an isolated centimeter cube of air by 0.1083 ergs, as calculated from the equation

$$E = \frac{0.1083}{\alpha_{2A}} \qquad (1)$$

where α_{2A} is the sum of the linear photoelectric absorption coefficient and the linear true absorption coefficient for air.

The absorption coefficients used here and throughout the rest of the paper were derived from the general equation given by Victoreen (*21*). A table of coefficients for air has recently been published (*22*) in which a correction was made for the effect of coherent scattering at the longer wavelengths. These values, although somewhat more accurate, are not used here because the coefficients usually enter as ratios with other coefficients which are not so corrected.

Most of the work discussed here is with reference to an X-ray source, but some discussion of γ-rays will be given.

Distribution of Intensity

When a beam of radiation passes through an absorbing medium there is a gradual decrease in intensity due to an increase in distance from the source and due to transformation of a part of the energy in the incident quanta into kinetic energy of electrons and energy of scattered radiation.

The intensity at any point within the medium could be readily calculated if it were not for the presence of scattering, since the decrease in intensity due to electron production and due to spreading of the beam follows laws which are well known. But, as the result of single and multiple scattering, each volume element of the fluid may receive energy indirectly from all parts of the sample, in addition to that received directly from the primary beam. For an extended medium exposed to a parallel beam, it has been shown experimentally that there is an exponential decrease in intensity with penetration, but the apparent absorption coefficient is considerably less than μ, the total absorption coefficient (*31*).

In addition, there is a change in the wavelength distribution of the radiation. If the initial beam is inhomogeneous, there is a shift of the energy distribution toward shorter wavelengths with increasing penetration, since the low-energy quanta are of relatively greater efficiency in the production of photoelectrons and are consequently removed more rapidly than those of higher energy. On the other hand, if the beam is initially monochromatic it will soon become inhomogeneous from the softening which accompanies scattering.

It is thus evident that for the general case neither the intensity nor the wavelength distribution can be accurately calculated for a point within an extended medium when scattering is present. However, some interesting approximations have been made (under special assumptions) for points on the beam axis by means of the method of isocontribution contours (*5, 6, 23, 24*).

The type of scattering that is referred to above is the Compton or incoherent scattering in which the incident quanta interact with free electrons in the absorber. This type of scatter always increases the wavelength.

There is also another type of scatter, the Thomson or coherent scattering, where the radiation interacts with atoms and the wavelength is unchanged. Absorption by the latter process is unimportant except for long wavelengths, and is then small by comparison with the photoelectric absorption; it will therefore be neglected.

It is of considerable advantage to have the intensity as uniform as possible throughout the sample, and improvement in this direction can be attained by a combination of bilateral irradiation together with heavy filtration to remove the softer components. An arrangement for bilateral irradiation as used in this laboratory is shown in Fig. 1, while the improvement in beam homogeneity by the use of filtration is illustrated for a 250-kv source in Fig. 4.

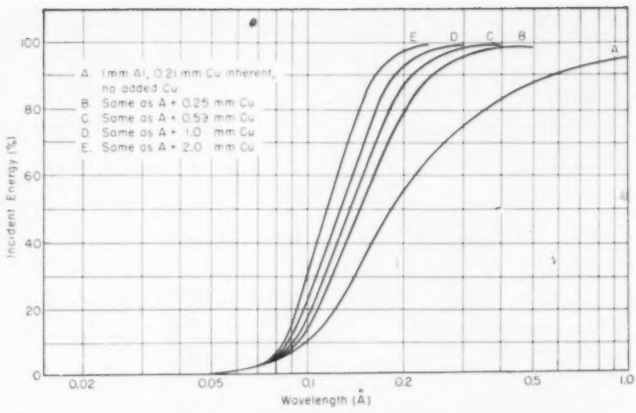

FIG. 4. Spectral distribution of radiant energy from a 250-kv X-ray generator

Heterogeneity of the Beam

As is well known, the output of radiant energy from an X-ray generator is made up of two parts, one of which is monochromatic and characteristic of the target, and the second of which is spread over a broad range of wavelengths and is independent of the target material. The first part is the characteristic or fluorescent radiation and the second is the continuous spectrum.

Around 98% of the total output is present in the continuous spectrum, which has a peak in the neighborhood of the cut-off wavelength, λ_0, but contains a considerable amount of energy out to much longer wavelengths. The distribution of energy over this spectrum can be determined by use of the filtration curve with some suitable absorber such as copper, according to a method suggested by Silberstein, and amplified by Bell, Jones, Greening, and Greenfield (*25–30*). The method consists in solving the integral equation

$$I(x) = \int_{\lambda} f(\lambda) e^{-\alpha_\lambda x} d\lambda \qquad (2)$$

for $f(\lambda)$ by the use of inverse Laplace transforms in conjunction with the filtration curve. In this equation, $I(x)$ is the intensity at distance x; $f(\lambda)d\lambda$ is the incident intensity for the range λ to $\lambda + d\lambda$; and α_λ is the sum of the photoelectric, true, and scattering absorption coefficients. Greenfield *et al.* (*30*) give some results in a useful form obtained by this treatment.

If irradiations are made with the γ-rays from radium filtered with 0.5 mm of platinum to remove α- and β-rays, the spectrum is not continuous but consists of a series of discrete rays which range in wavelength from 0.0056 to 0.067 Å as shown by the values in Table 1 (*32*).

If desired, the output can be made

TABLE 1—Gamma Rays from Radium

Wavelength (Å)	*Per cent of total energy*
0.0056	9.09
0.0070	25.37
0.0089	4.93
0.0100	4.36
0.0110	12.91
0.0132	3.49
0.0161	2.18
0.0203	22.36
0.0353	8.80
0.0420	4.24
0.0512	1.55
0.0671	0.12

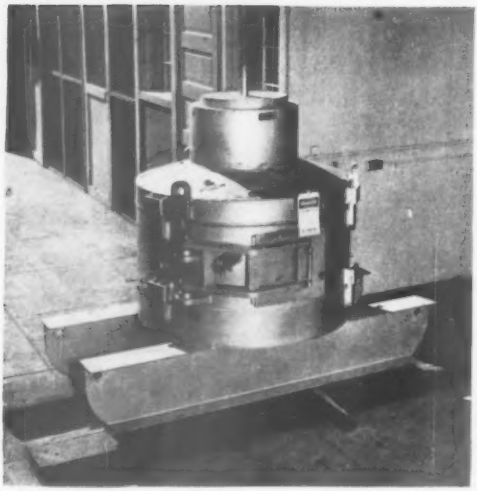

FIG. 5. A radium source used for chemical experiments

FIG. 6. A radiocobalt source that gives monochromatic radiation

quite homogeneous by additional filtration with platinum or lead. A radium source which is being used for chemical experiments in this laboratory is shown in Fig. 5. Figure 6 shows a radiocobalt source from which the radiation is nearly monochromatic at $\lambda = 0.0095$ Å.

The heterogeneity of the incident radiation affects the energy absorption in two ways: first through the effect on the intensity distribution, and second through the wavelength dependence of the absorption coefficients for air and for the medium. This will be illustrated next month in the section on calculations.

Absorption by Container

An approximate correction for the decrease in intensity of the incident radiation due to absorption by the container may be made by use of the coefficients appropriate to the wall material. The coefficient α_2 (the sum of photoelectric and true absorption coefficients) is preferred to the coefficient α_1 since the radiation scattered in the forward direction by the upper surface of the container becomes, in effect, a part of the main beam, whereas that scattered backward out of the liquid is compensated for, to a considerable extent, by backscatter into the liquid from the lower surface. The combination of these two effects has the result that there is not much energy removed from the beam due to scatter by the wall.

A plot of the function $e^{-\alpha_2 x}$ against wavelength for 1 mm of borosilicate glass (Pyrex brand chemical glass) is given in Fig. 7. Multiplication of the initial intensity by the appropriate ordinate of this curve will give the fraction which penetrates the glass, under the assumption of the preceding paragraph. The absorption-coefficient data are from Todd (*33*).

Electronic Equilibrium

To illustrate this effect, consider the passage of a beam of radiation from a vacuum into some material medium. Due to absorption of the radiation in the medium, electrons will be generated and many of them will move in the same direction as the radiation. Immediately adjacent to the interface there will be only a relatively few electrons, but with further penetration the number will increase until a condition is reached where the ratio of the number of secondary electrons to the number of primary quanta which traverse any cross section will approach a constant value. When this condition exists there is said to be electronic equilibrium.

Now if the radiation passes from this medium across an interface into a second medium which has a different effective Z and/or density, there will be a zone of transition until the point is reached where the ratio adjusts itself to a value appropriate for the second substance. The thickness of this zone is considered equal to the range of secondary electrons in the material.

The theory of the cavity ionization chamber was developed for a special

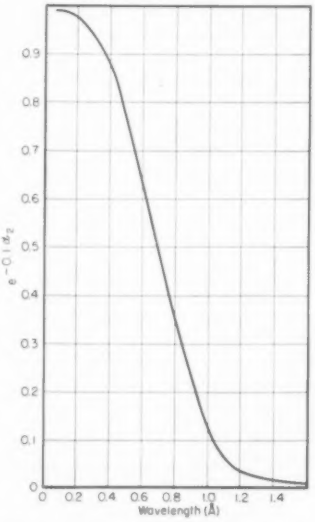

FIG. 7. Dependence of the function $e^{-0.1\alpha_2}$ on wavelength for borosilicate glass

kind of interface, namely that between a solid and a small air pocket contained therein. For this case, it has been shown (*34–39*) that the energy absorbed in a small volume of the irradiated medium can be calculated from

$$E = J\,W\,\rho \qquad (3)$$

where E is the total average energy absorption per unit volume, J is the number of ion pairs formed per unit volume of air, W is the energy required to form one ion pair, and ρ is the ratio of the energy absorbed from electrons per unit path length in the medium to the same quantity in air. Since the ionization in air can be readily measured, there is available a method for the determination of energy absorption in the solid.

Equation 3 has been found to be valid for γ-rays under the following conditions:

1. The dimensions of the cavity are small compared with the range in air of the electrons from the wall.

2. The effective atomic number of the wall material is nearly the same as that for air.

3. The wall is sufficiently thick, so that electronic equilibrium is reached in it before the radiation passes into the air cavity.

If the interface is between glass and an aqueous solution, as is often the case for radiation-chemistry experiments, the following data are pertinent:

$$\bar{Z}\ \text{(Pyrex glass)} = 10.48$$
$$n\ \text{(Pyrex glass)} = 6.78 \times 10^{23}$$
$$\bar{Z}\ \text{(water)} = 7.47$$
$$n\ \text{(water)} = 3.36 \times 10^{23}$$

where $\bar{Z}$ is the effective atomic number; n is the number of electrons per cm³. Since $\bar{Z}$ and n are larger for glass than for water (or aqueous solutions) the production of both photo- and recoil electrons will be greater in glass when the radiation traverses an equal thickness of the two media. The thickness required to produce electronic equilibrium is shown in Fig. 8 as a function of electron energy. The abscissae in this curve are for the effective range, and were calculated from data given by Lea (*41*).

The conditions in the transition layer may be inferred from some results obtained by Spiers (*42*) for the interface between bone and soft tissue. For low-energy radiation there is a decided difference between the equilibrium ionization level in the glass and

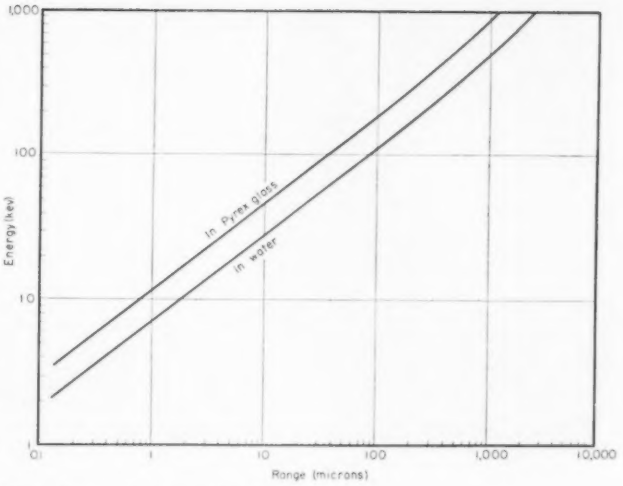

FIG. 8. Range-energy curves for electrons

that for the aqueous solution together with a thin transition layer. As the energy per quantum increases, the thickness of the transition zone grows larger, but there is a decrease in the ionization-level difference. The curve relating the level of ionization with distance from the interface is very steep for the first case, while for the second there is a more gradual decline.

The influence of this effect on the over-all chemical change will be determined by the ratio of the volume of the transition layer to the total solution volume, and accordingly becomes of more importance for small samples. However, small samples are desirable from the standpoint of escape of the scattered radiation and hence one is led to some ambiguity in the proper choice of sample volume.

* * *

The author is indebted to Dr. M. A. Greenfield for permission to reproduce Fig. 4, and to Dr. G. V. Taplin for permission to reproduce Fig. 5.

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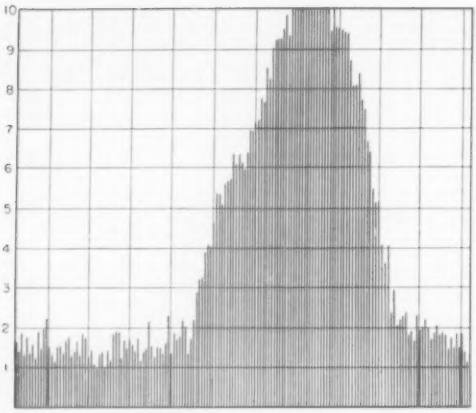
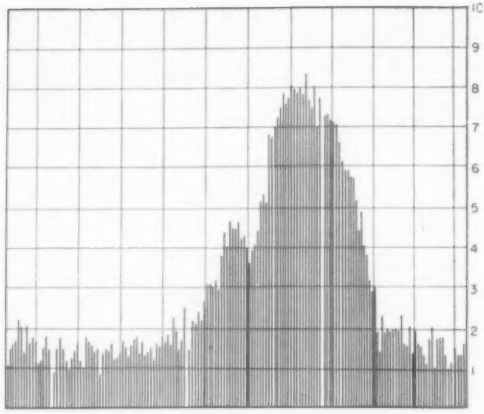


CHART RECORDED for a paper-strip chromatogram purported to contain a single radioactive component. In this case, no slit was used between counter window and paper strip. Compare with chart at right



SECOND RECORDING of same chromatogram charted at left. Slit 1 cm wide was used to protect counter window. Resolution of band of activity into at least two components can be seen

An Automatic Scanner for Paper Radiochromatograms

- Offers rapid localization of radioactive materials along a unidimentional strip
- Permits ready estimation of R_f values and relative abundances of radioactive material
- Provides permanent record of experiments

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Division of Nutrition and Physiology, The Public Health Research Institute of the City of New York, Inc.

DISTRIBUTING COMPOUNDS chromatographically on paper and studying the distribution of radioactivity on the chromatogram thus produced often proves to be the simplest method for demonstrating isotopic homogeneity of a material or identifying an isotopic product.

The procedure has the obvious advantage of requiring small quantities of material, but, in the past, has suffered from the disadvantage of being time-consuming because the available techniques for scanning were inefficient. Scanning such a strip has generally been accomplished either by autoradiography or by manual exploration with a Geiger counter. This is particularly tedious when dealing with samples of a low specific activity of a weak beta-emitter (C^{14}, for instance).

These factors, together with the paucity of material at any area and loss of radiation due to absorption by the paper itself, all tend to give low count rates.

An automatic device, which offsets these difficulties, has been constructed in this laboratory. It is used for localizing and measuring radioactivity along a unidimensional paper strip chromatogram. Apparatus to accomplish a similar purpose by a somewhat different method has been constructed in at least one other laboratory (*1*).

Components

Our instrument, as seen in the block diagram and photograph above, causes the paper strip to move continuously under a thin-mica-window Geiger counter shielded with two inches of lead.* The sample carriage of the shield has been replaced by a modified slide, equipped with glass rollers to

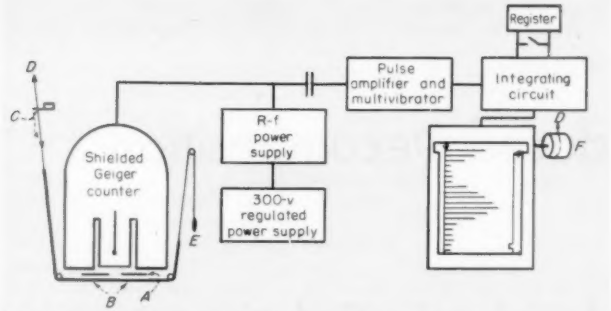

Diagram of automatic scanner seen in photograph at right. Radioactive materials are distributed on paper strip *B* that is drawn by cord *D* in front of counter window protected by slit *A*. Draw-cord *D* is wound on spool *F*, mounted on shaft of drum that moves chart of recording potentiometer. Tension on strip *B* is maintained by counterweight *E*. Automatic cut-off feature *C* includes adjustable stop on draw-cord that impinges on microswitch

guide the paper under the Geiger tube and maintain a constant geometry.

Movement of the paper strip is synchronized to the movement of the chart in a recording potentiometer.* The rate of progress of both the strip and the chart has provisionally been set at four inches per hour. When the scan is completed, a preset stop on the draw cord trips a microswitch and shuts off the electrical power.

The high-voltage supply to the Geiger tube is derived from an r-f power supply.* This in turn operates from the output of a regulated power supply.*

The pulses derived from the Geiger counter pass through a cathode follower and on through three stages of amplification. They then pass through a rectifier, the output of which actuates a multivibrator that drives a power amplifier. The amplifier in turn drives a relay (Western Electric 275C, with a refractory period of approximately 3 milliseconds) in series with a mechanical register that is normally shunted and is introduced into the circuit merely for calibration.

The relay actuates an integrating circuit, based on that described by Anger (*2*), in which pulses of uniform size are accumulated on a capacitor for a fixed time interval. Satisfactory values for the components in Anger's circuit for a low-counting-rate system were found to be: E_1, 1.5-volt battery; R_3, 2-meg adjustable potentiometer; R_4, 37 ohms; C_1, 0.05 μf; C_2, 8 μf (oil filled).

A one-rpm motor turns a cam that closes a microswitch at one-minute intervals to apply the accumulated capacitor voltage across the recording potentiometer. An instant later, the closure of a second microswitch momentarily discharges the capacitor to leave it ready to accumulate pulses for the next minute.

Operation

The pen of the recording potentiometer exhibits a fling at one-minute intervals. The height of the fling is approximately proportional to the number of pulses collected during the preceding minute. Fifteen flings correspond to one running inch of paper.

Sensitivity has been adjusted so that one inch in height corresponds to 20 counts per minute, and since the relationship between height and count rate is very nearly linear, this permits direct recording of count rates up to 200 cpm on the chart employed.

In view of the relatively large aperture of the Geiger tube window (1.1-inch diameter), considerable improvement in resolution is effected by the interposition of a metal slit between the window and the radiochromatogram. Whereas this has the effect of reducing the recorded count rate, it has on occasion permitted resolution into two components of what appeared initially as one broad peak. An example of such an instance is shown by the charts on the opposite page.

The random scatter of successive one-minute recordings is, of course, a function of the number of pulses accumulated. With the present background of 25 cpm, an increment of 10 cpm above background can be determined unequivocally. More favorable statistics can be attained by prolonging the time interval of integration. Thus the standard deviation is halved if pulses are collected for four minutes rather than one minute.

To facilitate estimation of R_f values (distance traveled by individual band divided by that traveled by solvent front), it has been found convenient to cement small pieces of aluminum foil to the edge of the chromatogram strip at the point of initial deposition of the sample and at the level of the final solvent front. These pieces of foil close a circuit as they pass before the Geiger counter and energize an accessory pen on the recording potentiometer. This permits evaluation of R_f values directly from the chart.

* Counter (GC-2) and lead (SC-9D) from Tracerlab, Inc., Boston, Mass.; recording potentiometer (Speedomax type G, 10 mv. full scale) from Leeds & Northrup Co., Philadelphia, Pa.; r-f power supply from Jerry's Radio Service, 166 Washington St., New York 6, N. Y.; regulated power supply (Lambda Rack Model 28) from Dubin Electronics Co., Inc., Corona, N. Y.

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AN APPROACH TO THE KINETICS OF

Radiation-Induced Decomposition of Certain Organic Molecules in Solution

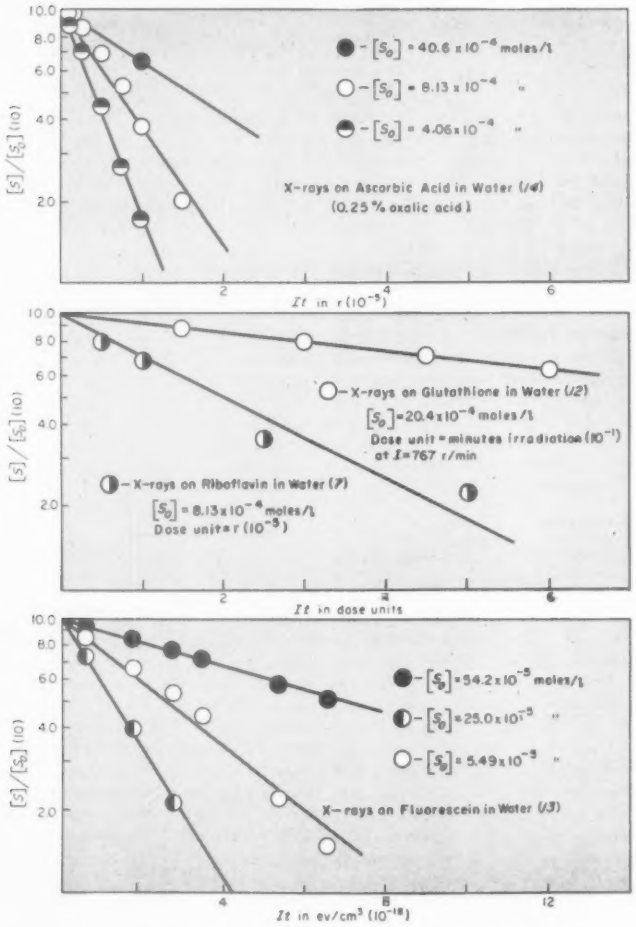
[S]/[S0] (10)
10.0
8.0
6.0
4.0
2.0
● - [S0] = 40.6 x 10⁻⁴ moles/l
○ - [S0] = 8.13 x 10⁻⁴ "
◓ - [S0] = 4.06x10⁻⁴ "
X-rays on Ascorbic Acid in Water (14)
(0.25 % oxalic acid)
2
4
6
It in r(10⁻⁵)
○ - X-rays on Glutathione in Water (12)
[S0] = 20.4 x10⁻⁴ moles/l
Dose unit = minutes irradiation (10⁻¹)
at I = 767 r/min
◑ - X-rays on Riboflavin in Water (7)
[S0] = 8.13x10⁻⁴ moles/l
Dose unit = r (10⁻⁵)
It in dose units
● - [S0] = 54.2 x10⁻⁵ moles/l
◐ - [S0] = 25.0 x10⁻⁵ "
○ - [S0] = 5.49x10⁻⁵ "
X-rays on Fluorescein in Water (13)
8
12
It in ev/cm³ (10⁻¹⁸)

FIG. 1. Typical data on effect of X-rays on various materials in water

A reaction mechanism is proposed that represents a distinct advance in systematizing the effects of radiation on a wide variety of systems in aqueous solutions

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When a solution is irradiated with high-energy electromagnetic or particulate radiation, it is generally observed that the solute concentration decreases with increased radiation dose.

Both linear (*1–4*) and exponential (*3, 5, 6*) disappearance-dose curves are obtained from experiments using dilute aqueous solutions, the linear usually occurring when the percentage of solute decomposed is small as compared with the total solute concentration present. Petroleum ether solutions of β-carotene show much the same behavior (*7*).

In some cases of concentrated aqueous solutions of inorganic solutes, the disappearance-dose curves may be essentially linear to a high percentage of inactivation (*8–10*). Hence, at sufficiently high concentrations, a zero- rather than first-order dependence on solute concentration appears to exist.

The experimental ionic yields in terms of molecules of solute decomposed per ion pair formed in the solution are observed to increase and approach relatively constant values as the initial solute concentration increases (*2–4, 6, 7, 9, 11–14*).

In concentrated aqueous solutions of inorganic solutes (region of zero-order dependence), the presence of oxygen is found to increase the initial value of the measured ionic yield (*1, 10*). As the dose is increased, however, the ionic yield assumes a value characteristic of an oxygen-free solution. This problem has received very little quantitative study, and almost no similar studies on dilute solutions have been made. Presumably, some such oxygen effect also occurs in nonaqueous media.

In an attempt to correlate the available data supporting these phenomena, a somewhat generalized reaction mechanism is proposed. The applicability and merit of this mechanism obviously lies in the agreement obtained between measured data and the corresponding calculated values.

Theory

The mechanism of the disappearance of solute from an irradiated solution has been attributed to an "indirect action" between activated solvent molecules and solute molecules (*15–20*). This conclusion follows from the fact that the partitioning of the incident energy between the solute and solvent is essentially determined by their weight fractions in the solution.

Hence, in the case of solutions, the process of irradiation at constant intensity may be considered to involve the formation and maintenance of a constant concentration of activated solvent molecules or radicals. A subsequent bimolecular reaction between these radicals and the solute present serves to deplete the concentration of the solute.

A study of the ultraviolet-absorption spectrum of water vapor subject to electron bombardment has confirmed the presence of the radicals H and OH. These radicals may be formed through both ionization and direct excitation processes, and evidence for their existence has been reviewed by Dainton (*17*). In the absence of experimental evidence concerning the condensed phase, it is reasonable to ascribe the observed oxidative and reductive power of irradiated water to the H and OH radicals present (*15, 17*).

The HO_2 radical has been postulated to exist in irradiated solutions containing dissolved oxygen (*10, 15, 16, 20*). In the following derivation, the radicals H, OH, and HO_2 will be assumed to be responsible for the observed indirect action.

Glocker (*21, 22*) has shown that H_2O_2 is both formed and decomposed during the irradiation of pure water containing dissolved oxygen. The reactions, $2H \rightarrow H_2$ and $2OH \rightarrow H_2O_2$, considered to be responsible for the decomposition of pure water (*3*), will be neglected in this discussion of solutions. The consequent interaction with the solute of any net H_2O_2 formed is thus neglected. When suitable data become available, the approximations assumed should be reassessed.

Consider that the following reactions are involved in the formation of the radicals in irradiated water (dilute solutions) containing oxygen,

$$H_2O \xrightarrow{cI} H + OH \quad (1)$$

$$H + OH \xrightarrow{k''} H_2O \quad (2)$$

$$H + O_2 \xrightarrow{k'''} HO_2 \quad (3)$$

where I is the constant radiation intensity, and c represents the solvent activation efficiency of the impinging radiation. The steady-state conditions are defined as

$$\frac{d[O_2]}{dt} = \frac{d[OH]}{dt} = \frac{d[H]}{dt} = \frac{d[HO_2]}{dt} = 0 \quad (4)$$

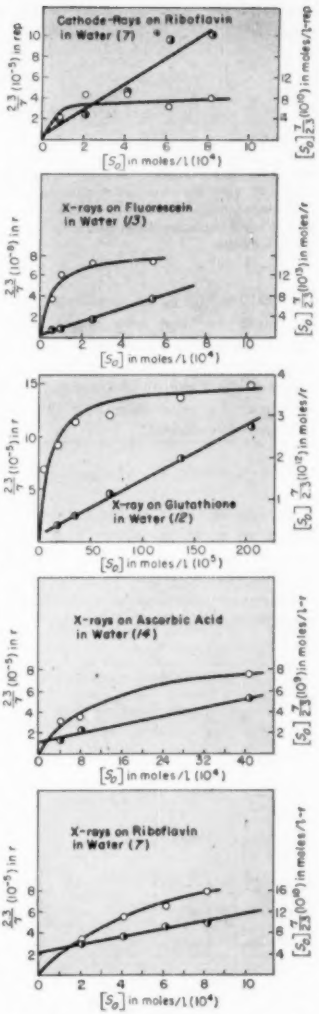
Cathode-Rays on Riboflavin in Water (7)
X-rays on Fluorescein in Water (13)
X-ray on Glutathione in Water (12)
X-rays on Ascorbic Acid in Water (14)
X-rays on Riboflavin in Water (7)
[S0] in moles/l (10⁴)
[S0] in moles/l (10⁵)

FIG. 2. Experimental values showing effect of cathode and X-rays on various materials in water. Half-filled circles apply to left ordinate; open circles, right

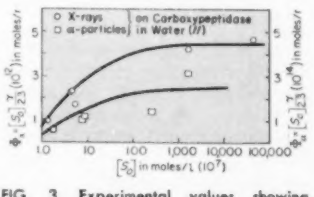

FIG. 3. Experimental values showing effect of irradiation of carboxypeptidase in water. Circles apply to left-hand ordinate, squares to right-hand ordinate

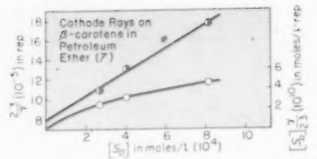

FIG. 4. Experimental values showing effect of cathode rays on β-carotene in petroleum ether. Half-filled circles apply to left-hand ordinate, open circles to right-hand ordinate

Now, let $[S_0]$ be the concentration of solute at time zero and $[S]$ be the solute concentration at a time t. Then the concentration of reaction products (inactive or decomposed solute) may be represented by $[S']$ so that, for all values of t,

$$[S] + [S'] = [S_0]$$

By considering that the first interaction of a solute molecule with a radical results in measurable inactivation but that subsequent undetectable interactions may occur, the following possible reactions may be listed

$$\mathrm{OH} + S \xrightarrow{k} S'$$

$$m\begin{cases} \mathrm{OH} + S' \xrightarrow{k} S' \\ \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \\ \mathrm{OH} + S' \xrightarrow{k} S' \end{cases}$$

$$\mathrm{H} + S \xrightarrow{k'} S'$$

$$n\begin{cases} \mathrm{H} + S' \xrightarrow{k'} S' \\ \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \\ \mathrm{H} + S' \xrightarrow{k'} S' \end{cases}$$

$$\mathrm{HO_2} + S \xrightarrow{k_1} S'$$

$$p\begin{cases} \mathrm{HO_2} + S' \xrightarrow{k_1} S' \\ \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \\ \mathrm{HO_2} + S' \xrightarrow{k_1} S' \end{cases}$$

where m = number of possible consecutive interactions of OH with an inactive solute molecule, n = number of possible consecutive interactions of H with an inactive solute molecule, and p = number of possible consecutive interactions of HO_2 with an inactive solute molecule.

Then if the change in concentration of S is being measured as a function of time at constant radiation intensity, the rate will be given by

$$\frac{d[S]}{dt} = -(k[\mathrm{OH}] + k'[\mathrm{H}] + k_1[\mathrm{HO_2}])[S] = -\gamma'[S] \quad (5)$$

The conditions imposed by Eq. 4 give

$$[\mathrm{OH}] = \frac{cI}{k''[\mathrm{H}] + k([S] + m[S'])} \quad (6)$$

$$[\mathrm{H}] = \frac{cI}{k''[\mathrm{OH}] + k'''[\mathrm{O_2}] + k'([S] + n[S'])} \quad (7)$$

$$[\mathrm{HO_2}] = \frac{k'''[\mathrm{H}][\mathrm{O_2}]}{k_1([S] + p[S'])} \quad (8)$$

To justify an integration of Eq. 5, it is convenient to rewrite the time-dependent terms in Eqs. 6, 7, and 8 as

$$[S] + m[S'] = [S_0] + (m-1)[S'] \equiv m'[S_0]$$

$$[S] + n[S'] = [S_0] + (n-1)[S'] \equiv n'[S_0]$$

$$[S] + p[S'] = [S_0] + (p-1)[S'] \equiv p'[S_0]$$

where m', n' and p' are considered to be constants. Equations 6, 7, and 8 may thus be written as

$$[\mathrm{OH}] = \frac{cI}{k''[\mathrm{H}] + m'k[S_0]} \quad (9)$$

$$[\mathrm{H}] = \frac{cI}{k''[\mathrm{OH}] + k'''[\mathrm{O_2}] + n'k'[S_0]} \quad (10)$$

$$[\mathrm{HO_2}] = \frac{k'''[\mathrm{H}][\mathrm{O_2}]}{p'k_1[S_0]} \quad (11)$$

which are rigorously true for $m = n = p = m' = n' = p' = 1$. With these parameters equal to unity, the agreement found with the available data was good. Thus the more general cases involving other values of the parameters were not treated.

Under these conditions, Eq. 5 integrates as

$$\ln \frac{[S]}{[S_0]} = -\gamma' t = -\gamma I t \quad (12)$$

where

$$\gamma = \frac{kc}{k''[\mathrm{H}] + m'k[S_0]} + k'c\left(1 + \frac{k'''[\mathrm{O_2}]}{p'k'[S_0]}\right) \times \left(\frac{1}{k''[\mathrm{OH}] + k'''[\mathrm{O_2}] + n'k'[S_0]}\right) \quad (13)$$

Hence, according to Eq. 12, an exponential dependence of concentration on radiation dose would be anticipated.

If the ionic yield is defined as

$$\Phi = \gamma[S_0] \quad (14)$$

then, from Eq. 13, the ionic yield is dependent upon the initial solute and oxygen concentrations. As the available data were measured under conditions of air saturation ($[\mathrm{O_2}] \approx 10^{-4}M$), any oxygen effect should be common to all. The observed variations in Φ should depend essentially on $[S_0]$ only.

Theory vs Experimental Data

Equation 14 predicts a dependence of ionic yield on the initial solute concentration of a given solution. This prediction is now compared below with the available experimental data.

In all cases of the data quoted, a line of slope γ was obtained by plotting $\ln([S]/[S_0])$ vs It. Figure 1 is a set of typical data. This exponential dependence is in agreement with Eq. 12.

By taking the reciprocal of γ, defined in Eq. 13, the following is obtained

$$\frac{1}{\gamma} = b[S_0] + a + \frac{d}{[S_0]} + \frac{f}{[S_0]^2} + \cdots \quad (15)$$

where a, b, d, and f are treated as constants. A consideration of the first two terms only gives

$$\frac{1}{\gamma} \approx a + b[S_0] \quad (16)$$

where $a = \frac{k'k''n'[\mathrm{H}] + kk''m'[\mathrm{OH}] + kk'''m'[\mathrm{O_2}]}{ckk'(m' + n')} - \frac{m'n'}{ckk'(m' + n')^2} \times \left(kk''[\mathrm{OH}] + kk'''[\mathrm{O_2}] + k'k''[\mathrm{H}] + \frac{kk'''m'[\mathrm{O_2}]}{p'}\right)$

and $b = m'n'/[c(m' + n')]$

Over the range of available experimental values, the validity of this approximation (Eq. 16) is shown in Fig. 2. Here a plot of $1/\gamma$ vs $[S_0]$ gives an essentially straight line with slope b and intercept a. This linear dependence is evidence in favor of the assumption that $[\mathrm{O_2}]$ remains essentially constant, according to Eq. 4, during irradiation.

By using the derived values of a and b in the expression

$$\Phi = \frac{[S_0]}{a + b[S_0]} \quad (17)$$

EXPRESSIONS Relating Ionic Yield to Initial Solute . . . and Apparent Solvent Activation Efficiency of High-Energy Radiation Impinging on Dilute Solution

Solute	*Solvent*	*Radiation*	$\Phi = \frac{\alpha[S_0]}{\beta + [S_0]}$ *in moles solute dissociated per energy unit*			$1/b(10^{12})$	c *in molecules solvent dissociated per 100 ev*
			α	β	*unit*		
Glutathione	Water	X-rays	8.68×10^{-12}	9.44×10^{-3}	r	8.68	5.2
Fluorescein	Water	X-rays	3.73×10^{-12}	4.68×10^{-5}	r	3.73	2.1
Carboxypeptidase	Water	X-rays	10.2×10^{-12}	4.44×10^{-7}	r	10.2	5.9
Riboflavin	Water	X-rays	9.50×10^{-12}	1.48×10^{-4}	r	9.50	5.5
Riboflavin	Water	3,000-kv cathode rays	4.62×10^{-12}	4.03×10^{-5}	rep	4.62	2.2
Ascorbic Acid	Water (0.25% oxalic acid)	X-rays	2.26×10^{-12}	1.18×10^{-2}	r	2.26	1.3
Carboxypeptidase	Water	radon α's	5.58×10^{-14}	4.86×10^{-7}	r	0.0558	0.029
β-carotene	Petroleum ether	3,000-kv cathode rays	5.78×10^{-12}	6.72×10^{-4}	rep	5.78	3.4

the curves appearing in Figs. 2 and 3 were calculated. The agreement between the calculated and experimental points is, in general, good.

Figure 4 represents the application of Eqs. 16 and 17 to the results of the irradiation of a solution of β-carotene in petroleum ether. Apparently an indirect action somewhat analogous to that occurring in aqueous solutions is operative in this case.

The table above gives the derived expressions for Φ as a function of $[S_0]$. Here $\alpha = 1/b$ and $\beta = a/b$.

An approximate value of c, the solvent activation efficiency of the radiation acting on the dilute solution in terms of molecules solvent dissociated per 100 electron volts of absorbed energy, may be obtained from the experimental values of b where $b = (m'n')/[c(m' + n')]$. Use of the previous values of $m' = n' = 1$ gives $c = 1/2b$. The values of c so obtained are also listed in the table.

Weighting equally the rather scattered values for cathode rays and X-rays in the table, one obtains an average value of $c = 3.6$. Interestingly enough, essentially the same value, 3.7, has been obtained independently in some recent unpublished data (*23*) of Hochanadel and Hart who studied the radiation-induced decomposition of water.

A consideration of multiple interactions, $m'n'\ (m' + n') = 55$, gives $c \approx 3.6$ for α-irradiation.

Conclusions

A mechanism for the radiation-induced decomposition of solute in dilute aqueous solution has been proposed and an expression for the ionic yield, Φ, as a function of the initial solute concentration, and the oxygen concentration has been derived. This mechanism, with appropriate intermediates, may be considered to serve as a prototype for radiation-induced reactions measured in petroleum ether solutions.

Experimental data obtained by irradiation of aqueous solutions of glutathione (*12*) and fluorescein (*13*) with X-rays, aqueous and petroleum ether solutions of certain vitamins (*7*, *14*) with X- and cathode rays, and aqueous solutions of the enzyme carboxypeptidase (*11*), with X-rays and α-particles have been analyzed in terms of this proposed mechanism. The agreement between the calculated and the observed values of Φ as a function of the initial solute concentration is close.

As dilute solutions were involved in the data, the radical-forming efficiency of the impinging radiation upon the solvent should be of the order expected when no solute is present. For X- and cathode-ray irradiation, the calculated values average 3.6 water molecules dissociated per 100 ev of energy expended in aqueous solution. This value is in good agreement with a recent unpublished value of 3.7 water molecules dissociated per 100 ev expended in pure water (*23*).

The calculated radical-forming efficiency of α-particles on aqueous solutions of carboxypeptidase tends to indicate the existence of multiple interactions of a single solute molecule with a number of activated solvent molecules or radicals.

* * *

The authors wish to acknowledge the valuable discussions and advice gained in the seminars on radiation effects given at the University of Utah under the direction of Dr. John Z. Bowers, Dean of the College of Medicine. Thanks are also due Dr. Betsy J. Stover of the Radiobiology Laboratory.

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Production Testing of Multiplier Phototubes

Production control tests are used to maintain and improve the desirable characteristics of multiplier phototubes. A new test of cathode sensitivity to blue light correlates well with results obtained with phosphors. An understanding of these tests will benefit the user

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CORRELATION of operating data with a knowledge of the tests used during production to assure uniformity of multiplier phototubes enables the experimenter to obtain more valid results. This article discusses the more pertinent design and production tests applied in the manufacture of 5819 tubes.

Cathode Sensitivity

Cathode sensitivity is of primary importance for scintillation-counting applications because the output pulse height relative to the background noise is directly proportional to this characteristic (*1*). Several production tests are used to check this parameter.

Spectral response. The spectral response characteristic of the tube, shown in Fig. 1, is suitable for operation with many of the blue-emitting phosphors (*2*). In production, tubes are sampled to check for spectral sensitivity. The range of variation encountered is indicated by the dashed lines in Fig. 1.

Absolute sensitivity. The absolute sensitivity of each cathode is determined by measurement of its luminous sensitivity. The standard for this test is a tungsten lamp calibrated with a National Bureau of Standards lamp to a color temperature of 2,870° K. A radiant flux of 0.01 lumen is used, and the tube is connected as a diode with all dynodes tied together to serve as an anode. This relatively large amount of flux for a multiplier phototube is necessary to facilitate direct measurement of the cathode current, but would overload the tube if it were operated as a multiplier phototube.

When the 5819 was first introduced, the minimum limit for cathode sensitivity was 8 μa/lumen. The present minimum limit is 20 μa/lumen and the average sensitivity 40 μa/lumen, as shown in the production distribution curve for cathode sensitivity, Fig. 2.

Blue sensitivity. Most phosphors used in scintillation counters peak in the blue and near ultraviolet, but the tungsten lamp used in testing cathode sensitivity peaks in the red and near infrared. In an attempt to achieve better correlation with actual use, a Corning 5113 filter is used with the tungsten lamp. This combination provides a peak in the region corresponding to the light emitted by many phosphors, as shown in Fig. 3.

Figure 4 is a sampling graph of recent production that indicates the variations in blue sensitivity. Tubes that have the same response to tungsten light show a wide range of blue sensitivity. The dotted lines in Fig. 4 are equal per cent transmission; the average is about 10%.

Since the results shown in Fig. 4 correlated quite well with pulse-height resolution data obtained by users of the 5819 tubes, the test of blue sensitivity has now been included in routine production testing. A lower limit of 2 μa/lumen has been established. Previously, blue sensitivity ranged from 0.5 to 5 μa/lumen; now the best is 8 μa/lumen, with an average blue sensitivity of 3–5 μa/lumen.

Anode Sensitivity and Gain

The anode sensitivity is a product of the cathode sensitivity and the gain of the ten dynode stages. The anode sensitivity is measured directly on all 5819 tubes with 90 volts per dynode stage and at an illumination of 10^{-2} lumens on the cathode. This light

SIGNAL-TO-NOISE RATIO and collection efficiency are measured in production testing with this apparatus. R. W. Engstrom adjusts multiplier phototube for test. Light from tungsten lamp in box passes through rotating-disk chopper and filters and impinges on cathode of tube

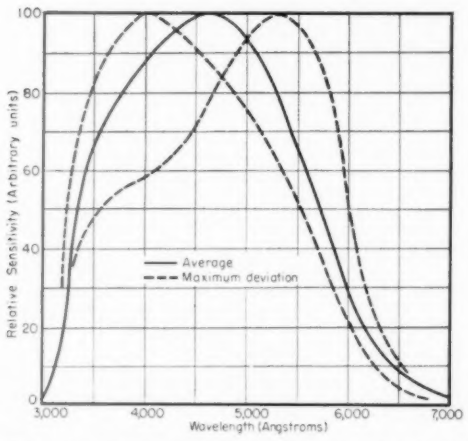

FIG. 1. Spectral response of 5819 multiplier phototubes, showing range of observed variations

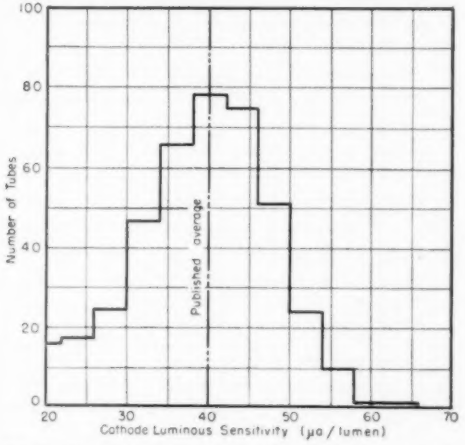

FIG. 2. Distribution of cathode sensitivity in production sample of 403 type-5819 tubes

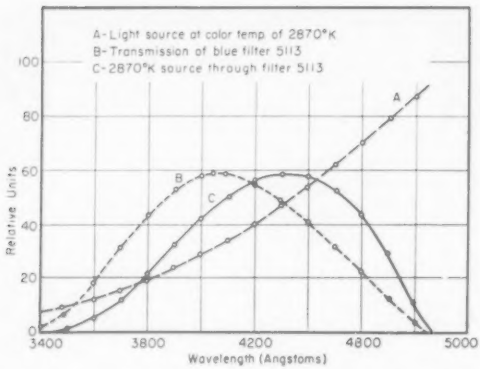

FIG. 3. Spectral plot for tungsten lamp with and without Corning 5113 filter

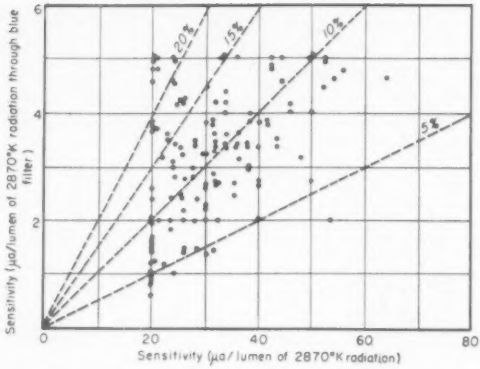

FIG. 4. Relation of tungsten to blue sensitivity for production sample of 5819 tubes

level is obtained by means of a divergent lens system from the same tungsten source used for the cathode-sensitivity measurements. A distribution curve showing the present range of anode sensitivity is shown in Fig. 5. Although no production test is made for gain, the current amplification averages approximately 600,000 at 90 volts per stage.

Dark Current and High Voltage

In the 5819, it has been possible to maintain the original low maximum limit for dark current of 0.05 μa at 90 volts per stage, even though the sensitivity and gain have been increased.

High-voltage operation of the 5819 is limited to a range within which a regenerative type of dark current is not encountered. Because any regenerative breakdown of the tube is directly determined by the gain, a sliding-scale breakdown test is specified as a function of the tube gain. The scale for the test is shown in the table on the next page.

As might be expected, because of the relatively large size of the 5819, high-voltage breakdown is a greater problem than in smaller tubes. At the present time a study is being made of high-voltage operation with the anticipation of improving the tube so that larger output pulses may be delivered without erratic noise generation. To reduce feedback, improved internal shielding has recently been added to the 5819 construction.

Signal-to-Noise Ratio

Closely related to the dark-current tests of the 5819 is a test of the anode sensitivity with respect to the noise in the dark current. The signal-to-noise test is a direct measure of the usefulness of the 5819 tube in the detection of low light levels. The anode dark current is partly due to ohmic leakage, but the dark current contributed by amplified thermionic emission (3) is more troublesome in low-level measurements such as pulse counting. The thermionic emission from the cathode amplified by the multiplier section produces pulses in the anode circuit which may be analyzed as shot noise.

In the production test, noise is measured in a bandwidth of 1,000 cps; the published value of Equivalent Noise Input (ENI)*, however, is quoted for a bandwidth of 1 cps. The light source for this test is a tungsten lamp at a color temperature of 2,870° K; flux is reduced to 10^{-7} lumen by means of mirrors and a neutral-density filter. Light modulation at 90 cps is provided by a rotating light chopper. Operation is at 90 volts per stage.

The minimum test limit for signal-to-noise ratio is the equivalent of an ENI of 3×10^{-11} lumen. However, since the principal source of dark noise in the 5819 is thermionic emission from

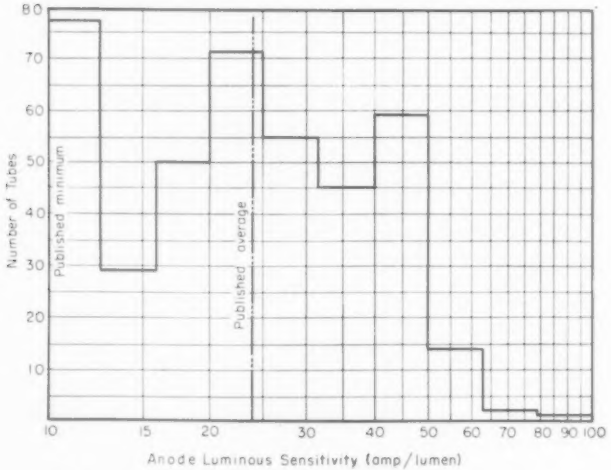

FIG. 5. Distribution of anode sensitivity for 403 type-5819 tubes

* ENI is defined here as the input signal in lumens which would produce a response just equal to the noise in the tube in a bandwidth of 1 cps.

the cathode, improvement could be obtained by careful cooling of the tube (*3*).

Collection Efficiency

Although the properties discussed thus far contribute to increased efficiency of a scintillation detector, the benefit of high cathode sensitivity may be lost if an inefficient electron focusing and collecting system is used. If the cage mount is not centered, the focal point for the photoelectrons on the first dynode may not be the spot of maximum efficiency. In a very poor alignment, the electrons might actually strike the shield instead of the first dynode. Even when the tube is mounted accurately, it has been possible for the mount to be shifted by a hard bump. Recent designs incorporate a strengthened assembly to prevent such movement.

In a laboratory method of measuring collection efficiency in the multiplier phototube, demonstrated by Morton (*1*), the number of amplified electron pulses at the anode is compared with the measured cathode emission in units of electron charges. This method, however, is not used for production testing.

The production test used measures the ratio of the output signal to noise in the signal. This test correlates directly with what might be termed effective cathode sensitivity (cathode sensitivity × collection efficiency). The following discussion analyzes the relation between the test indication, S/N_s, and the collection efficiency of the first dynode stage.

The mean square noise current, $(I_n^2)_{avg}$, in the output of a multiplier in a band width Δf is given by

$$(I_n^2) = 2\mu^2 e I_k \Delta f \left(1 + \frac{B}{m-1}\right) \quad (1)$$

Test Voltages for Sliding-Scale Breakdown Test

Gain	*Over-all test voltages*	*Maximum permissible anode dark current* (μa)
0.1–0.25 × 10^6	1,400	5
0.25–0.4 × 10^6	1,350	5
0.4–0.6 × 10^6	1,300	5
0.6–1.0 × 10^6	1,250	5
1.0– × 10^6	1,200	5

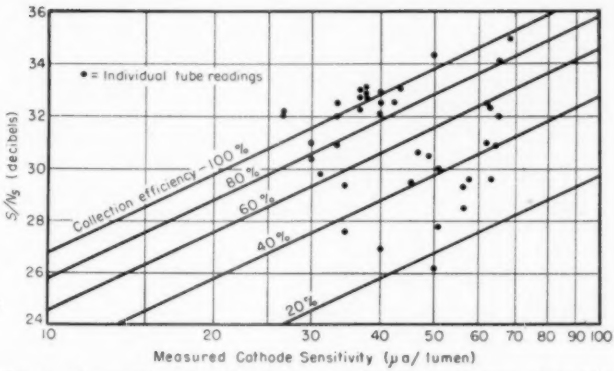

FIG. 6. Electron collection efficiency as determined by measurement of cathode sensitivity and of the ratio of signal to noise in the signal

where μ is the over-all multiplier gain, m is the gain per stage (assumed to be uniform), e is the electron charge, and I_k is the cathode emission current collected by the first dynode. (Some of the electrons emitted by the cathode may be collected by the shield and other parts which do not provide secondary emission.) The parenthetic quantity $[1 + B/(m-1)]$ is the factor of noise increase due to the random character of secondary emission. A recent measurement by Morton (*1*) shows $B = 1.54$ for type 5819. If $m = 4$ and an output load resistance of R is assumed for the multiplier, the approximate value of the mean square noise voltage output $(V_n^2)_{avg}$ is given by

$$(V_n^2)_{avg} = 3R^2\mu^2 e I_k \Delta f \quad (2)$$

The collection efficiency of the multiplier tube is obtained by comparing this noise output voltage with a useful signal output voltage. The anode signal current, I_b (for a d-c test), is equal to μI_k, and the corresponding output voltage equals $\mu R I_k$. If the light is now chopped to produce a square wave of frequency, f, so that the undistorted peak-to-peak output voltage is V_b, and an effective output capacitance of C is assumed, the rms value of the distorted square wave is given by

$$\sqrt{(V_b^2)_{avg}} = \frac{\sqrt{2}\,V_b}{\pi}\left\{\frac{1}{1+(2\pi fRC)^2} + \frac{1}{3^2[1+(3\cdot 2\cdot \pi fRC)^2]} + \frac{1}{5^2[1+(5\cdot 2\pi fRC)^2]} + \cdots\right\}^{1/2} \quad (3)$$

In the present 5819 test, $f = 90$ cps $\Delta f = 1/4RC$ or 1,000 cps, and thus

$$\sqrt{(V_b^2)_{avg}} = 0.477\,V_b = 0.477\mu R I_k \quad (4)$$

The ratio of signal to noise in the signal, S/N_s, may be expressed in decibels as

$$\frac{S}{N_s} = 10\log_{10}\frac{0.477^2 I_k}{3e\Delta f} \quad (5)$$

If the measured cathode current is I_{km} and ϵ is the efficiency of collection of photoelectrons at the first dynode, the effective cathode current I_k is equal to ϵI_{km}. The effective cathode current is less than the measured cathode current by that amount of current collected by tube parts such as the shield or the grid wires. If the value for bandwidth and the test-condition illumination of 10^{-7} lumen are substituted in Eq. 5, and if I_{sm} is the measured cathode sensitivity in microamperes per lumen, then

$$S/N_s = 10\log_{10}(\epsilon I_{sm}) + 16.76 \quad (6)$$

The collection efficiency, ϵ, may thus be determined from the measurement of S/N_s and I_{sm}.

Figure 6 illustrates the application of Eq. 6 for S/N_s to the determination of collection efficiency. Contour lines are shown for constant collection-efficiency values. The plotted points represent data on recent production of the 5819. Points above the line marked 100% collection efficiency result from a probable error in measurement of the order of 0.5 to 1.0 db.

Data on collection efficiency versus

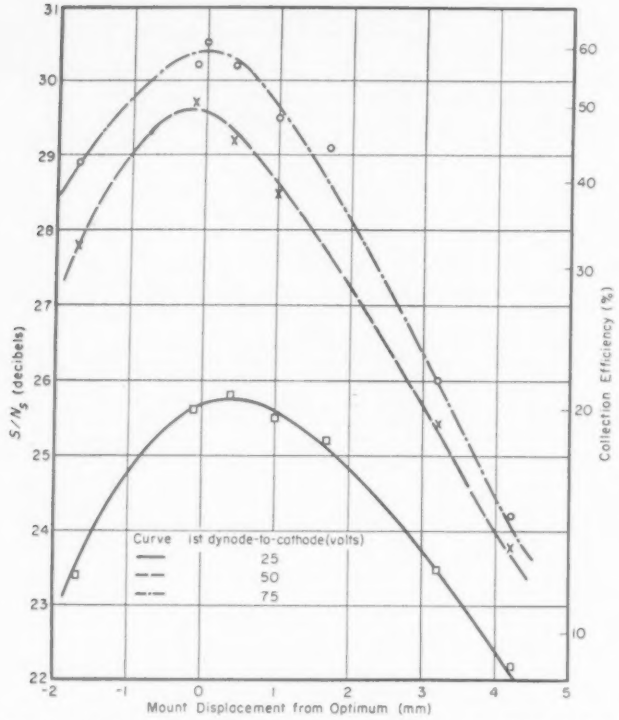

FIG. 7. Variation of collection efficiency with mount displacement and cathode-first-dynode voltage for early version of 5819 tubes. Positive values are displacement away from anode side of dynode cage

mount position and cathode-to-first-dynode voltage, shown in Fig. 7, were obtained on earlier production samples of the 5819 mount which could be shifted by external bumping. A light spot was used which illuminated practically the whole cathode. Mount displacement from the optimum position was measured optically with a cathetometer.

A test limit has been set on the value of S/N_s (26 db minimum) rather than on collection efficiency since S/N_s is a direct measure of effective cathode sensitivity. This test also serves as a check on mount positioning which might result in poor focusing.

Magnetic-Field Considerations

Collection efficiency may be reduced by the presence of magnetic fields. Because of the relatively large spacing in the 5819 between the cathode and the first dynode, a small magnetic field may cause appreciable deflection of photoelectrons. The effect is most pronounced when the electrons are deflected along the width of the first dynode by a magnetic field parallel to the axis of the dynode cage.

The sensitivity to such a magnetic field is shown in Fig. 8 for the 5819. Since the magnetic field of the earth is of the order of 0.8 gauss, certain alignments may affect the operation of the 5819. In critical applications it may be advantageous to provide magnetic shielding. The effectiveness of one and two-layer mu-metal shields is indicated in Fig. 9.

It is possible to reduce the magnetic-field sensitivity by increasing the voltage applied between cathode and first dynode. Effectiveness of this procedure is also illustrated in Fig. 8. The asymmetries observed result from some misalignment of the mount structure and from the effect of the horizontal component of the earth's magnetic field. A voltage of 150 volts is recommended as a suitable value to be applied between cathode and first dynode.

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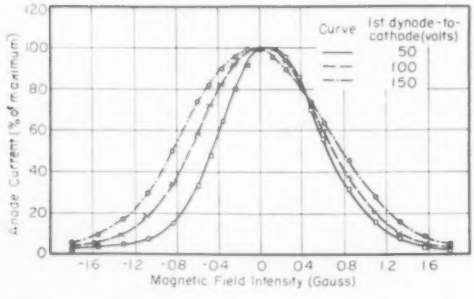

FIG. 8. Sensitivity of 5819 tube to magnetic fields showing variation with cathode-first-dynode voltage. Magnetic field is parallel to dynode-cage axis

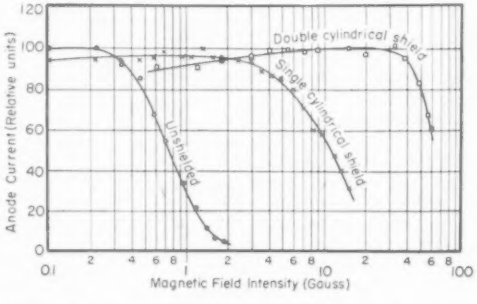

FIG. 9. Effectiveness of 0.045-in. mu-metal shielding in reducing magnetic sensitivity of 5819 tubes. Magnetic field is parallel to dynode-cage axis

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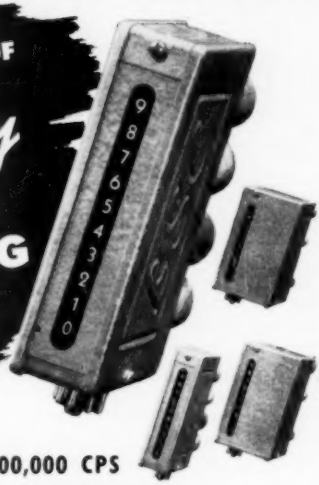

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Prevention of Side Effects in Sterilization of Foods and Drugs by Ionizing Radiations

By B. E. PROCTOR
and S. A. GOLDBLITH

Department of Food Technology
Massachusetts Institute of Technology
Cambridge, Massachusetts

In 1948, research was initiated in the Food Technology Laboratories at the Massachusetts Institute of Technology to obviate the side effects produced by ionizing radiations when used to sterilize foods and tissues. These side effects are undesirable, as they cause changes in flavor, color, and sometimes texture.

It has been shown that these side effects may be minimized by irradiation of foods in the frozen state (*1*). However, although this procedure may minimize, it may not prevent entirely the formation of off-flavor, and freezing is undesirable for some types of foods because of other physical changes caused thereby.

In 1948 and 1949, Proctor and Goldblith (*2, 3*) reported the results of investigations with high-energy X-rays and cathode rays in which they found that niacin (a relatively radioresistant vitamin) protected ascorbic acid (a relatively radiosensitive compound) when both were irradiated together. For example, they found that as little as 10 μg of niacin per ml would protect ascorbic acid in a concentration as great as 500 μg per ml.

Examination of the results of similar experiments on these and other compounds, together with a detailed investigation of radiochemical phenomena from both the theoretical and the experimental points of view, has provided a rational basis for approaching the problem.

When high-energy radiations strike matter (e.g., food), the microorganisms in the food are destroyed in the main by direct hits on or very near them. At the same time free radicals are

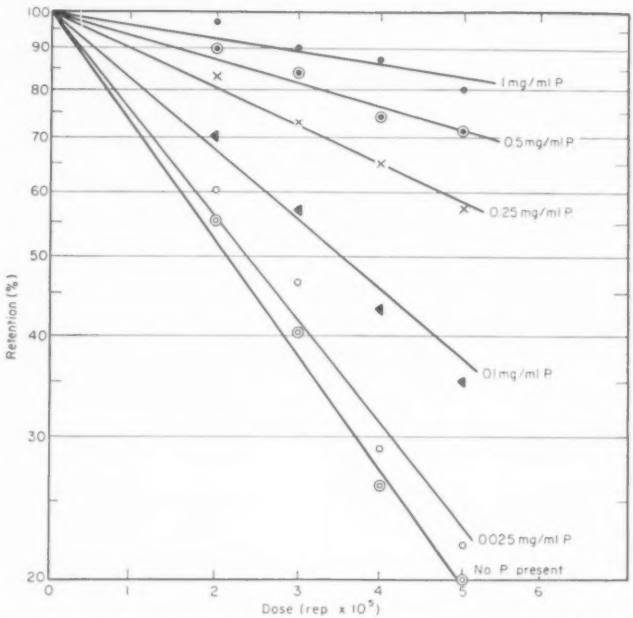

FIG. 1. Effects of 3-Mev cathode rays on crystalline pepsin in acetate buffer (pH 4.3) and in the presence of varying quantities of sodium d-iso-ascorbate

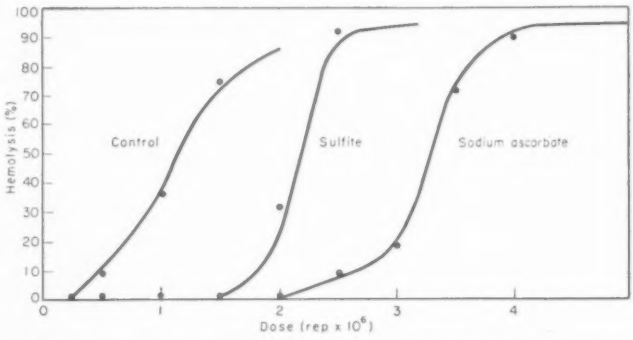

FIG. 2. Effect of cathode rays on hemolysis of 5% red blood cells (bovine) in phys. saline

produced in the solutes that may be present. These free radicals can then interact with the solutes and cause either oxidation or reduction, cleavage of bonds, and the like.

The reactions of high-energy radiations in water may be illustrated as follows:

When water is bombarded by ionizing radiations, a positive water ion is formed and an electron is liberated

$$H_2O \rightsquigarrow H_2O^+ + e^- \quad (1)$$

The electron reacts with another molecule of water, forming a negative water ion

$$e^- + H_2O \rightarrow H_2O^- \quad (2)$$

The positive water ion dissociates into a hydrogen ion and a free hydroxyl radical

$$H_2O^+ \rightarrow H^+ + [OH] \quad (3)$$

The negative water ion dissociates into an hydroxyl ion and a hydrogen atom

$$H_2O^- \rightarrow OH^- + [H] \quad (4)$$

The hydroxyl radical is a strong oxidizing agent and will oxidize any oxidizable solute. The hydrogen atom is a strong reducing agent and, as such, will reduce any reducible solute. If no oxidizable or reducible solutes are present, these free radicals may recombine to form water again

$$H + OH \rightarrow H_2O \quad (5)$$

Although these illustrations are simplifications of the complicated processes that occur, they do in the main represent the more important over-all reactions that take place.

When a food is bombarded by ionizing radiations and an off-flavor occurs, this change may be represented by

$$\text{Flavor molecule} + [OH] \rightarrow \text{oxidized off-flavor} \quad (6)$$

If, on the other hand, there is mixed with the food some compound that will act as a free-radical acceptor (FRA) and compete with the flavor molecule for the [OH] radical, it should be possible to minimize or reduce the off-flavor so that it is so slight as to be undetected by experienced taste panels who are familiar with the off-flavor that might otherwise occur

$$\text{Flavor molecule} + [OH] + \text{FRA (reduced)} \rightarrow \text{Flavor molecule} + \text{FRA (oxidized)} + OH^- \quad (7)$$

The authors have successfully accomplished elimination of off-flavor, in the case of several foods, by using ascorbic acid, d-iso-ascorbic acid, and their salts. For example, chopped luncheon meat has been treated with sterilizing doses of high-energy cathode rays; there has been no off-flavor. This was accomplished by intimately mixing into the meat prior to irradiation one of these compounds.

A quantitative demonstration of this process is presented in Fig. 1. Crystalline pepsin in dilute solution is radiosensitive. With the addition of small amounts of sodium d-iso-ascorbate, it was possible to protect the pepsin.

To be of value, a free-radical acceptor should be effective in low concentrations, should be nontoxic, and should be readily miscible with the material to be protected. Ascorbic acid and its analogs and derivatives are well suited for this purpose.

Among other side effects that have been observed is the hemolysis of red blood cells that have been exposed to ionizing radiations. The authors have found that when red blood cells (5% suspension in saline) are irradiated with cathode rays, 50% of the blood is hemolyzed at a cathode-ray dose as low as 1.25×10^6 rep, but when sodium ascorbate is added to the suspension of red blood cells, 50% hemolysis does not occur until the dose is as great as 3.5×10^6 rep (Fig. 2).

Other ramifications of this technique and its effective action will be reported in more detail later.

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Hood for Radioactivity Work

By S. H. WEBSTER, E. J. LILJEGREN, and C. C. POWELL*

National Institute of Arthritis and Metabolic Diseases
National Institutes of Health, Bethesda, Maryland

The design of laboratory fume hoods is governed by several important considerations, the usual ones being economy or space limitations. However, in laboratories using radioactive materials the prime consideration is that of safety of the workers. In equipping existing buildings with hoods it is likely that some compromises must be made, due either to the restrictions imposed by available air supply or space. However, in designing a new building, to be used exclusively for the study of radioactive materials, it is possible to arrange the rooms and facilities around the hoods.

During the planning stage of the Isotope Laboratory at the National Institutes of Health in Bethesda, Maryland, the underlying philosophy was that in so far as possible all manipulations with radioisotopes should be carried on within fume hoods. Accordingly, these hoods should provide ample working space, should be capable of easy and rapid decontamination in case of accidental spills, should provide good visibility, should be sturdily constructed to allow heavy shielding to be added if necessary, and, above all, should provide safety by permitting the removal of toxic fumes and dusts without the possibility of these materials entering the room. Since the conditioned air in these laboratories was not to be recirculated, all of the room air was to be exhausted through the hoods.

In addition to these requirements, there was the additional one of filtering the exhausted air to remove radioactive material before discharging the air to the outside. The filters selected for this purpose were Chemical Corps duplex units consisting of a M-3 paper filter followed by a charcoal M-8 unit. However, experience with corrosive materials, such as fuming nitric and

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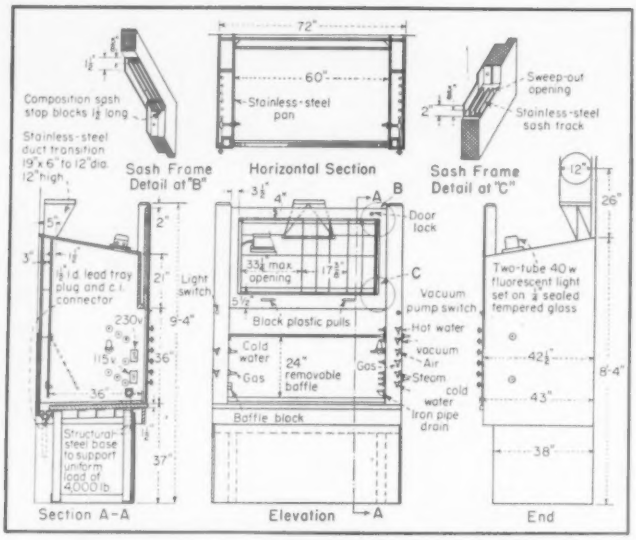

FIG. 1. Details of fume hood

perchloric acids, has indicated the desirability of using spun-glass filter units under these operating conditions.

For safety and flexibility of operation, each of the 15 hoods was provided with a separate blower and set of filters. The size of the former was determined not only by the face velocity desired at the hood opening, but by the amount of conditioned air available and also the pressure drop introduced by the filters. This pressure was equivalent to about 5 in. of water initially. However, due to the high cost of the filters it was desirable to permit them to be used after an appreciable increase in resistance had occurred, due to accumulation of dust. Hence, blowers capable of exhausting 900 ft³/min at a pressure of 10 in. of water were provided. A face velocity of 150 ft/min had been found to give satisfactory hood operation. Consequently, to insure that this velocity could be attained, even with an increase in filter resistance, the hood opening was limited to about 6 ft².

The type of hood utilizing the forced-jet principle of exhaust (sometimes called a pressurized hood) was not adopted because of the possibility of exhaust fan failure. If this occurred, with the high resistance across the filter bank, leakage of radioactive material into the room might present a serious hazard.

The advantages of a hood 6 ft in length are apparent, provided that access to any part of it is convenient and quick. Furthermore, for complicated arrangements of apparatus that are even longer, continuous working spaces are sometimes desirable and double hoods are often an advantage. With this feature in mind, the three hoods in each of the five laboratory rooms were arranged so that two were side by side, the third being placed on an opposite wall. By means of a removable panel assembly, to be described, it was possible to have a space in the hoods more than 11 ft long and about 3 ft wide by 5 ft high, with a constriction in the center.

The essential features of the hoods now in use are shown in Fig. 1. The working surface is a stainless-steel watertight pan or tray provided with a trough along the rear edge and an opening into the radioactivity drain, this opening under ordinary circumstances being closed by a removable stainless-steel expansion drain plug. There is a total slope of ½ in. front to back; this permits drainage of liquid from the front of the hood in case of spillage.

The superstructure, baffles, aprons, front and side panels and countertop are fabricated of sanded cement-asbestos board treated with a black resin coating and baked to give surfaces which are highly acid-, alkali- and solvent-resistant. The minimum thickness of all this material is ⅜ in., the countertop being 1¼-in. thick. The finish of the material is suitable for the repeated application of strippable plastic paint without damage to the original finish. This permits the interior to be decontaminated by removal of the strippable coating. In practice, with the exception of the windows, the light and the cup sink, the entire interior of the hoods including the service outlets and the tray is sprayed with the plastic material.

Utilities

The customary utilities—air, gas, vacuum, cold and hot water, and steam—are furnished as shown. The serrated tips as well as the knob controls are color-coded for easy identification, the latter also being named. In addition, two spare tips extend through the wall to provide means of introducing or withdrawing water or other noncontaminated liquid wastes or a gas without the use of a rubber tube through the hood opening. A cup sink above the working surface provides a drain for condenser water. Since high-pressure air is rarely needed within the hood, the air outlet is supplied with an adjustable pressure reducer capable of furnishing air at 5–20 lb/in². To avoid electric cord connections from the outside of the hood, duplex electric outlets on either side supply both 115 or 220 volts a-c.

The vacuum outlet, instead of being connected to the house vacuum line, is attached to a vacuum pump located in the base of the hood, the exhaust being vented behind the hood baffle. The motor for this pump is actuated by a switch on the right column above the knob controls.

The light switch on the left column, for the fluorescent light assembly, completes the array of controls. The blower switch is not located on the hood but is mounted on the wall because of wiring considerations peculiar to this installation.

The face opening of this hood is controlled by three ¼-in. tempered plate-glass panels, each sliding in a separate stainless-steel track mounted in the sash frame. These panes can be moved to provide a maximum opening of approximately 3 × 2 ft at any place along the front and can be easily removed by lifting them from the track.

Tempered plate glass was selected rather than wire-mesh glass or the laminated type (so-called safety glass)

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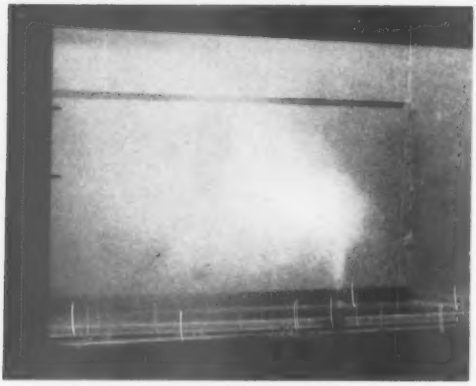

FIG. 2. Performance test of hood with sash raised

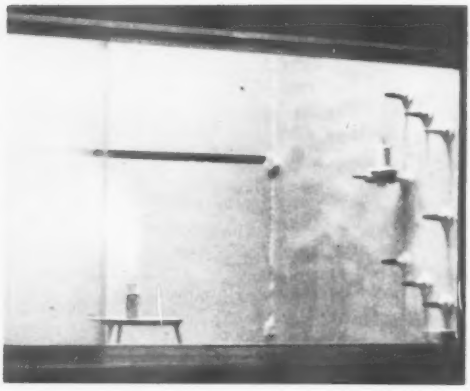

FIG. 3. Performance test for maximum panel opening

following tests of windows in mock hoods. Detonation of an explosive mixture in a glass flask inside each hood provided sufficient impact to break the window. Many large sharp fragments of the wire glass were thrown out with great violence, whereas with the tempered-glass window only small particles having rounded edges were produced. Consequently the danger from flying glass appeared to be considerably less with the tempered plate glass than with the other two types. Fragmentation of the tempered plate glass, due to scratching with hard objects, such as grit or diamond, is a possibility but has not been experienced.

Adjustable counterbalancing weights, together with a stainless-steel cable, allow the hood sash to be easily raised when desired. The maximum face velocity is secured by lowering the sash which can be locked by the monitor in this position by means of a push-type sliding-door key lock. A stop at either side of the sash prevents complete closure of the face.

A notable feature of this hood is the introduction of a stainless-steel strip on the two sides, top and bottom of the sash. The purpose of these sharp edges is to increase the velocity of air flow at these points, thus producing considerable turbulence. Tests have shown that these strips are very effective in preventing reverse flows. This turbulent flow appears to be superior to the more streamline flow obtained with the usual type of opening.

The hood is provided with a furnace-type gravity-operated by-pass damper which opens when the glass panels are nearly closed. This inexpensive control effectively reduces the velocity of the air movement through the hood opening and prevents the building up of excess vacuum within the hood.

Each hood is provided with a straight vertical baffle. Since the opening at the bottom has been found not to be critical, means of varying this opening are not provided.

The double hood is essentially two hoods placed side by side, but with the controls reversed on the hood located on the left. In addition, each half of the double hood is provided with a removable end panel held in place by a single tie bolt, the space between the panels being sealed with cement-asbestos board.

Some of the operating characteristics of the hood can be seen from the photographs made under different conditions. Figure 2 was taken with the panels adjusted for maximum opening, while Fig. 3 was taken with the sash raised. Figure 4 shows the flow at an edge of the face opening.

Working with the sash down is desirable when maximum protection is needed. However, it is often more convenient to operate with the sash raised; this can be done safely when using low-level material. Under these conditions the face velocity is reduced to approximately 60 ft/min. As can be seen from Fig. 3, removal of fumes is satisfactory. However, some reversal of air flow into the room may occur when rapid movement takes place along the face of the hood.

In planning for laboratories for use in the Radiation Wing of the Clinical Center at the National Institutes of Health, a number of modifications have been made.

To provide for easier access to plumbing, the services on the left side of the right-handed hood and on the

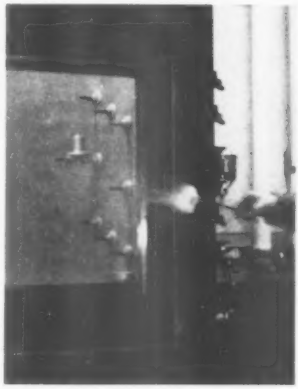

FIG. 4. Test of air flow at edge of face opening

right side of the left-handed hood have been eliminated and an external panel has been provided adjacent to the control valves. Two cold-water outlets have been furnished, the hot-water facility being omitted. The cup drain has been enlarged to give a 3×6-in. oval cup sink. The single vacuum and steam outlets and the double spare outlets have been retained. The bottom and top parts of the sash have been narrowed to $3\frac{1}{2}$ in. The base panels on the front of the hood are hinged for easier access to the vacuum pump.

The trough at the rear of the stainless-steel pan has been reduced in height so as to make it easier to remove the pan from the hood during decontamination or renewal of the strippable plastic coating. Finally, to indicate that the hood is in operation and actually pulling air, a pneumatically operated switch and pilot light have been added.

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BOOKS

Advances in Biological and Medical Physics, Vol. II, edited by John H. Lawrence and Joseph G. Hamilton, Academic Press Inc., New York, 1951, xi + 348 pages, $7.80.

This volume, the second of a projected series of which the first was published in 1948, contains nine articles purportedly (from the title) concerned with advances in biological and medical physics.

Three or more of the articles might more rightly be placed in a volume on the application of chemistry to biological problems. An isotope is an isotope even if it is radioactive. The use of an electronic circuit to detect it does not make the experiment a physical rather than a chemical one, just as the use of a microscope in counting blood cells does not make a red count a problem in physics.

Six of the articles are concerned with the application of nucleonics to biological problems.

This predominance perhaps reflects current trends in biological and medical research, but there are other aspects of biophysics. The latter are represented by the inclusion of such papers as the *Molecular Exchange and Blood Perfusion Through Tissue Regions* and *Biophysical Approaches to Atherosclerosis.*

In the chapter on *The Biological Effects of Radiations,* H. J. Curtis presents a lucid discussion of the physical and biological properties of alpha and beta particles, gamma- and X-rays, and fast and slow neutrons. Delayed in appearance (the article was originally prepared for inclusion in 1948 in Volume I of this series), it contains elementary radiobiologic background material which has been presented in many forms in recent years. However, in a clear, concise exposition, the author has presented a surprising amount of pertinent factual material on the physical and technical aspects of the subject. The section on physiological effects appears dated in view of the developments within the years since the preparation of the manuscript, but this is a minor defect.

The Application of the Carbon Isotopes to a Study of Animal Metabolism is covered by Charles Heidelberger. Following a brief but important section on the various carbon isotopes, methods of presentation of measurement data, and the labeled compounds synthesized to the date of writing, the author has assembled the *in vivo* and *in vitro* investigations in the literature since Vennesland's review appeared in Volume I through to July, 1949. The uses of carbon-14 and carbon-13 in studies of fatty-acid oxidation, glycolysis, fat metabolism, transmethylations, amino acid reactions, protein synthesis, and purine and pyrimidine synthesis are competently handled. The section on pharmacology, however, appears to be sketchy, due, perhaps, to the scarcity of material.

In similar outline, Harold Tarver treats the subject of *Radioactive Sulfur and Its Applications in Biology.*

The article on *The Radioautographic Technique* by Dorothy Axelrod Heller is a good survey of the technique and is highly recommended for those interested in using this method to localize radioactive elements. After short statements on such subjects as the relation of the ionizing particles involved, factors affecting resolution, film requisites, exposure time, and developing, the author describes, in greater detail, some of the methods successfully employed to date. A brief resumé of the literature in which radioautographs have been used concludes this presentation. The reviewer feels that this article is all too brief.

One of the hazardous aspects of radiations is their carcinogenic action. This timely subject is reviewed by Austin M. Brues in the article *Carcinogic Effects of Radiation.* The carcinogenic effects of total-body irradiation, of locally directed radiation, and of absorbed radioelements are presented along with a discussion of the mechanism of radiation carcinogenesis, latent period, threshold, etc. The article is notable for the inclusion of recent work on the problems of deposited radioelements such as plutonium, phosphorus, strontium, and carbon. The latter, despite its long half-life, appears not to be especially hazardous because of the rapid loss of C^{14} from the body.

Those interested in measurements of isotopes *in vivo* with externally placed instruments will find the article on *In Vivo Studies with Radioisotopes* by Enrique Strajman and Nello Pace particularly helpful. The sections concerned with the various physical and biological factors and the present limitations of this rapidly developing method are particularly illuminating.

In the article on *Radioactive Isotopes in Clinical Diagnosis,* Edith H. Quimby presents a brief summary of the methods in use for radioactive iodine, phosphorus, sodium and iron.

Atherosclerosis has been the subject of numerous researches by a team of workers whose spokesman is John W. Gofman. In *Biophysical Approaches to Atherosclerosis,* he presents the findings of this group and demonstrates the use of the ultracentrifuge in the elucidation of the mechanism of a pathological condition. In a notably concise manner, he has presented the theoretical and experimental background of this important series of experiments.

The distribution of circulating blood and the exchange of its contained substances have been receiving increasing attention in recent years. In *Molecular Exchange and Blood Perfusion Through Tissue Regions,* Hardin B. Jones has collated his own data and that of others on gas exchange and other molecular exchange with a short section on changes in regional perfusion with age. Particularly informative are the sections on iodine exchange, thyroid blood perfusion, and sodium exchange.

All in all, the volume consists of several good reviews of respective fields. Whether this type of presentation is as good as, or better, than the continuing type of review such as appears in the "Annual Reviews" of biochemistry and physiology is a debatable question.

—Abraham Edelmann
Biology Department
Brookhaven National Laboratory
Upton, New York

The Measurement of Radio Isotopes, by Denis Taylor, John Wiley & Sons, Inc., New York (or Methuen & Co., Ltd., London), 1951, vii + 118 pages and 40 diagrams, $1.50.

The author, who is head of the electronics division of the Atomic Energy Research Establishment at Harwell, England, has written this pocket-size (11 × 13 cm) book on the measurement of radioisotopes and addressed it to the nonspecialist in the field. Within its 118 pages are packed a surprising amount of information, succintly and clearly written.

A brief mathematical introduction is followed by two chapters on counting

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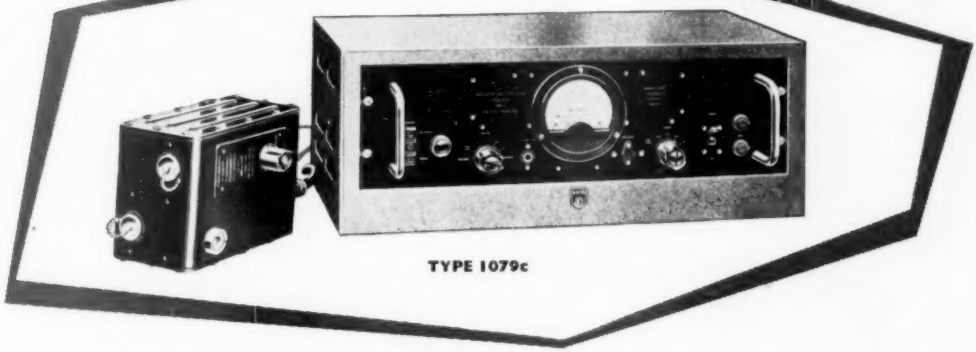

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THIS instrument has been designed in conjunction with the British Atomic Energy Establishment, expressly for measuring the small direct currents and voltages encountered in Nuclear research. It can be used as a replacement for most electrometers and has a zero drift of only 1 to 2 mV per day. Direct indication of the voltage or current being measured is given on the panel meter; simultaneously a 1 m.a. or 100 millivolt recorder may be operated.

Four voltage ranges are provided — 0–30, 0–100, 0–300 and 0–1000 millivolts. There are three switched input resistors, their value being 10^8, 10^{10} and 10^{12} ohms respectively. In its most sensitive conditions the Electrometer gives a full-scale deflection for a current of 0.03 micro-micro-amps.

For operation 110–115 and 200–250 volts A.C. 40–60 cycles.

Catalogue and further details can be forwarded on application.

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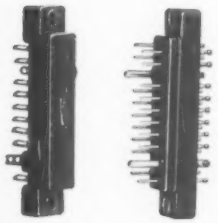
AN Originally designed for Army-Navy Specification requirements. Now used widely for instruments. Connects and disconnects by screw action of threaded coupling ring. Made in 2 plug types—3 receptacles with variations and accessories, in 15 shell sizes and more than 200 insert arrangements.

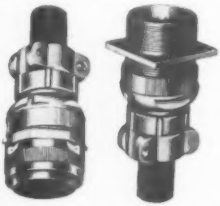
K Light weight, aircraft type connector ideal for many instruments. Connects and disconnects manually. Is held together by Acme thread coupling ring. Made in 7 shell types in 8 different diameters and more than 190 insert arrangements.

GS Hermetically sealed by use of glass fused to shell and contact, both machined from cold rolled steel. Made in 2 shell types —10 diameters and currently having 30 layout arrangements. Additional arrangements are being designed.

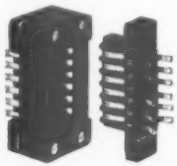
RS Hermetically sealed with special resilient rubber inserts. Specially adapted to aircraft relays and other sealed components. These fittings mate with standard "AN" Connectors having corresponding inserts.



DPM This series used primarily on electronic equipment where a multiple contact, rack and panel connector of extremely small dimensions is required. Both plug and receptacle are rigidly mounted. Connect and disconnect automatically when assemblies, to which they are mounted, are joined or separated. Made in 2 sizes having 2 contact arrangements.



AN-M For the tough jobs. Moisture-proof, vibration-proof and pressurized. Radio shielding is provided and all threaded parts are drilled for safety wiring. Connect and disconnect by screw action of threaded coupling ring. The variety of sizes and layout arrangements is nearly as great as the AN line.



RTC Is a quick disconnect requiring low separation force and having simple mounting requirements for chassis or wall types. Moisture drain holes provided in receptacle section. Plug section provides for lacing down wires after soldering. Made in five sizes.

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systems. Standards for counting, the effects of source geometry, and self-absorption are discussed, together with the techniques of measurement and various correction factors that are generally applied to the observed counting rate.

References, however, are treated rather sketchily; individuals and companies are frequently referred to by name only. The beginner would be helped additionally had the author prepared a selected bibliography or reading list for those who wished to pursue the subject farther.

The standardization of radioactive sources is treated in four short pages. Progress in this field has advanced considerably since the manuscript for the book was completed in September, 1950, and the reader is left with the impression that the standardization of radioisotopes is pretty much of a mystery. For the initiate, an additional table listing the availability of standards of radioactivity would have been helpful.

The work of the International Committee on Radiation Protection is not mentioned in the short section dealing with safe and hazardous amounts of radioactive material.

In spite of these shortcomings, caused primarily by the rapidity with which the field of atomic energy moves, the reviewer welcomes the appearance of such a handy little manual. Its convenient dimensions insure that it will find its way into the pocket of a reader rather than onto his bookshelf.

—GEORGE G. MANOV
Chief, Advisory Field Service Branch
Isotopes Division
U. S. Atomic Energy Commission

BOOKS RECEIVED

Science and Humanism (Physics in our Time), by Erwin Schrödinger, Cambridge University Press, New York, 1951, 68 pages, $1.75. This is a very readable pocket-size, illustrated, edition of four public lectures given by the author at University College, Dublin. He depicts the present situation in physics as it forms "part of man's endeavor to grasp the human situation."

The Principle of Relativity (reissue), by A. Einstein, H. A. Lorentz, H. Minkowski, and H. Weyl, Dover Publications, Inc., New York, 1923, vii + 216 pages,

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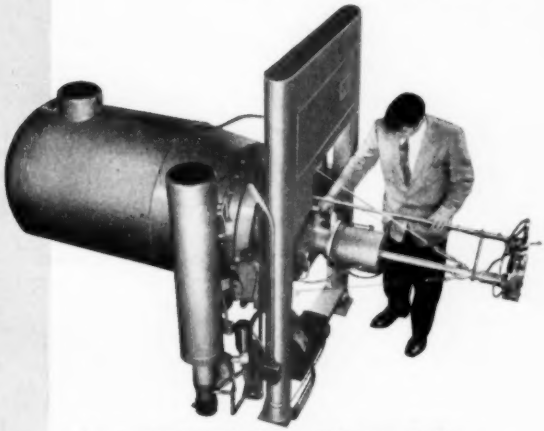

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Servomechanisms, Inc.,...pioneers in the design and production of packaged function "building blocks" for electronic and electro-mechanical control systems. Each block in the system is an individually packaged function easily plugged-in or out of pre-wired chassis. This technique simplifies maintenance and reduces the "down-time" problem to minutes. Both 60 and 400 cycle blocks are available for system synthesis. Servomechanisms' packaging technique provides the military and industrial designer with:

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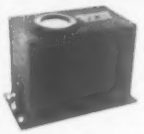

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paperbound, $1.50. This inexpensive reissue of the original collection of memoirs on the special and general theory of relativity, with notes by A. Somerfeld, and translated by W. Perrett and G. B. Jeffrey, is particularly suitable as a student's text and where hard usage is not expected. (A clothbound edition is also available at $3.50.)

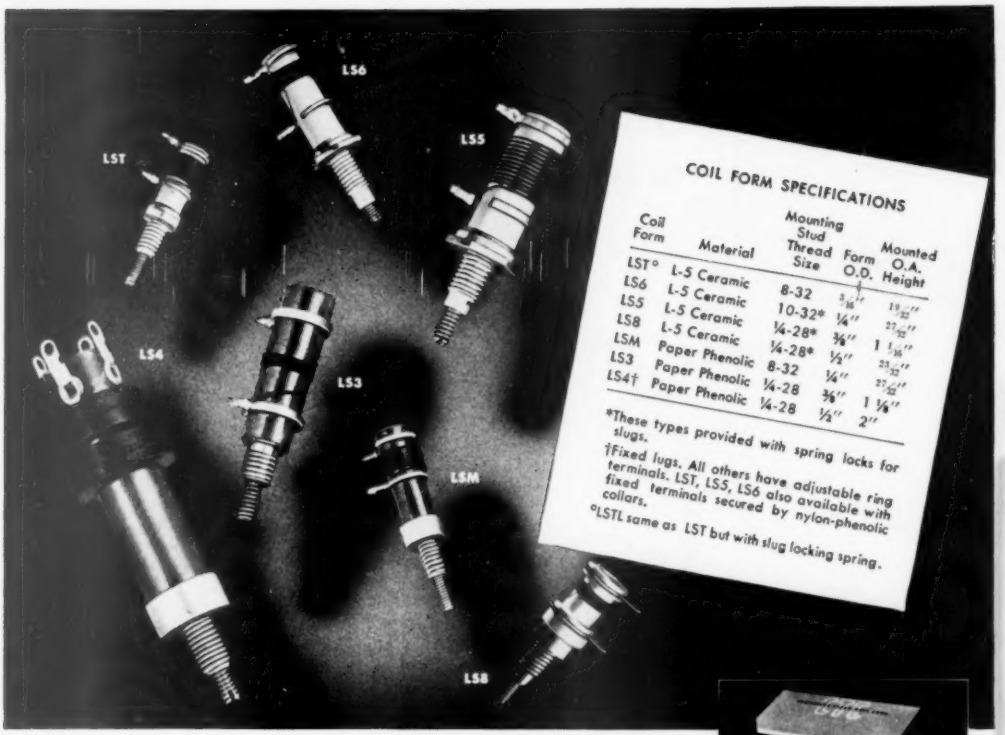
Industrial Ventilation—A Manual of Recommended Practice (2d edition). A wire-bound book intended as a ready source of recent data on exhaust ventilation. Information on hood and duct design, make-up and recirculated air, construction specifications, testing systems, fans, and air cleaning devices is included in 11 well-illustrated sections. A bibliography and appendix provide additional data. It is published by the American Conference of Governmental Industrial Hygienists. *Committee on Industrial Ventilation, P. O. Box, 453, Lansing, Mich., $3.*

OTHER LITERATURE

Prospecting for Uranium (revised edition). This is the booklet jointly published by the Atomic Energy Commission and the U. S. Geological Survey, the first edition of which sold 77,000 copies. The new edition contains eight color reproductions of common uranium-bearing ores hitherto unpublished, the latest official AEC price circulars, bonus information, and a compilation of public land orders listing tracts withdrawn from public use. *GPO, Washington 25, D. C., $0. 45, 25% off on lots of more than 100.*

List of 22 Patents and 1 Application for Patent Released for Public Use by the AEC (Vol. II, No. 1, February 19, 1952). *Issued by Chief, Patent Branch, Office of the General Counsel, U. S. Atomic Energy Commission.*

Instrument Servomechanisms (PB 104 386). This is a 265-page text devoted exclusively to servomechanisms used for automatic positioning. The behavior of servomechanism systems and components is explained by analogy with the actions in electronic circuits. Prepared by William J. Deerhake and Albert C. Ball and published by the Special Devices Center of the Office of



COIL FORM SPECIFICATIONS

Coil Form	Material	Mounting Stud Thread Size	Form O.D.	Mounted O.A. Height
LST°	L-5 Ceramic	8-32	3/16"	19/32"
LS6	L-5 Ceramic	10-32*	1/4"	27/32"
LS5	L-5 Ceramic	1/4-28*	3/8"	1 1/16"
LS8	L-5 Ceramic	1/4-28*	1/2"	23/32"
LSM	Paper Phenolic	8-32	1/4"	27/32"
LS3	Paper Phenolic	1/4-28	3/8"	1 1/8"
LS4†	Paper Phenolic	1/4-28	1/2"	2"

*These types provided with spring locks for slugs.

†Fixed lugs. All others have adjustable ring terminals. LST, LS5, LS6 also available with fixed terminals secured by nylon-phenolic collars.

°LSTL same as LST but with slug locking spring.

Here are the coils you want ...the way you want them!

Take advantage of one of C.T.C.'s most popular and useful services . . . the winding of slug tuned coils to exact specifications. Single layer or pie types furnished. You can be sure your specs — military or personal — will be faithfully followed to the last detail of materials and methods, and with expert workmanship.

C.T.C. coil forms are made of quality paper base phenolic or grade L-5 silicone impregnated ceramic. Mounting bushings are cadmium plated brass and ring type terminals are silver plated brass. Terminal retaining collars of nylon-phenolic also available in types LST, LS5, LS6.

Wound units can be coated with durable resin varnish, wax or lacquer. Both coils and coil forms are furnished with slugs and mounting hardware — and are obtainable in large or small production quantities. Be sure to send complete specifications for specially wound coils.

All C.T.C. materials, methods, and processes meet applicable government specifications. For further information on coils, coil forms or C.T.C.'s special consulting service, write us direct. *This service is available to you without extra cost.* Cambridge Thermionic Corporation, 467 Concord Avenue, Cambridge 38, Mass. West Coast manufacturers, contact: E. V. Roberts, 5014 Venice Blvd., Los Angeles, and 988 Market Street, San Francisco, California.

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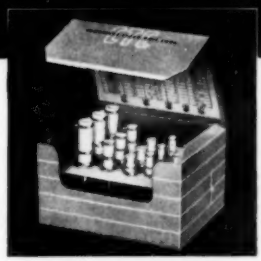
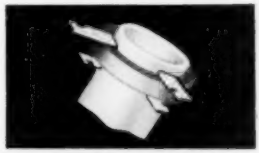


NEW CERAMIC COIL FORM KIT. Helps you spark ideas in designing electronic equipment or developing prototypes and pilot models. Contains 3 each of the following 5 C.T.C. ceramic coil form types: LST, LS5, LS6, LS7, LS8. Color-coded chart simplifies slug-identification and gives approximate frequency ranges and specifications. Nylon-phenolic collars to replace metallic rings available with kit for all ceramic coil forms except LS7 and LS8.



NEW NYLON-PHENOLIC COLLARS. Terminals held securely; soldering spaces doubled; excellent for both bifilar and single pie windings. Show an increase in Q and many new benefits over metallic rings — without impairing in any way the moisture- and fungus-resistant qualities of coil form assemblies.

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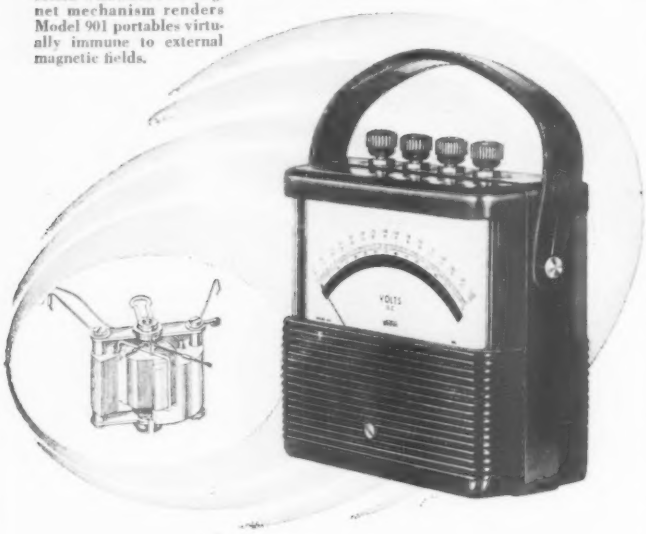
* The high degree of shielding obtained with the perfected WESTON core magnet mechanism renders Model 901 portables virtually immune to external magnetic fields.



For years instrument engineers have tried to build the magnet inside the moving coil for a more compact, more stable, inherently shielded d-c mechanism. In the Model 901 d-c portable instruments, Weston provides a practical and proved design of this type. The Weston core magnet construction gives uniform flux field over a wide deflection angle . . . withstands extreme mechanical abuse . . . and is exceptionally well shielded without increase in size and with a reduction in weight. Be sure to get the details of this remarkable development from your local Weston Representative, or write Weston Electrical Instrument Corporation, 583 Frelinghuysen Avenue, Newark 5, New Jersey . . . manufacturers of Weston and Tagliabue instruments.

WESTON *Instruments*

Naval Research, it is especially useful as a primer for personnel who must service such units. *Office of Technical Services, Dept. of Commerce, Washington 25, D. C., $2.*

BOOK NEWS

• **Nuclear data.** *Nuclear Science Abstracts* is now publishing summaries of new nuclear data compiled by the National Bureau of Standards Nuclear Data Group. Previous data collected by the NBS group were contained in "Nuclear Data," NBS Circular 499 with its three supplements (see NU, Feb. '52, p. 70), the third of which is now in press.

• **Annual review.** Volume 1 of a new publication, "Annual Review of Nuclear Science," will come off the press shortly. Prepared under the editorial supervision of the Committee on Nuclear Science of the National Research Council of the National Academy of Science, it contains 26 review articles by leading scientists in the field. It will be published by Annual Reviews, Inc., Stanford, Calif., which since 1931, has been publishing annual reviews of the current literature in other major fields of science.

Future volumes of the "Annual Review of Nuclear Science" will appear under the direction of James G. Beckerley (Atomic Energy Commission) as editor, and Donald F. Mastick (Atomic Energy Commission), Martin D. Kamen (Washington University), and Leonard I. Schiff (Stanford University) as associate editors. C. D. Coryell (Massachusetts Institute of Technology), L. F. Curtiss (National Bureau of Standards), E. Segrè (University of Illinois), R. E. Zirkle (University of Chicago), and Dr. Schiff will service on the editorial committee.

• **Journal name change.** The name of the official organ of the American Roentgen Ray Society and the American Radium Society has been changed to *The American Journal of Roentgenology, Radium Therapy, and Nuclear Medicine.* In editorial comment in the January, 1952, issue, it was explained that the last three words were added to the journal name in recognition of "the importance of radioisotopes and the rapidity with which they have been employed within recent years, not only in diagnostic procedures but also as therapeutic agents."

NEW SAFETY-DESIGN FUME HOOD for handling Radioactive Isotopes

Design approved for use by Oak Ridge Institute of Nuclear Studies

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- Low Velocity . . . operates with less than half the CFM of air needed on a conventional type hood.
- Air current directed across working surfaces removes heavy gases.
- Entire interior of hood is stainless steel for easy decontamination.
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Precision built by Kewaunee Mfg. Co., one of America's oldest and largest makers of fine Laboratory Equipment, including all types of Stainless Steel Equipment for Radioactive Laboratories.

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NUCLEONIC EVENTS

EUGENE M. ZUCKERT is sworn in as AEC commissioner by Supreme Court Associate Justice Stanley Reed at recent ceremony as AEC Chairman Gordon Dean looks on

Zuckert Takes up Duties as Member of the Atomic Energy Commission

Eugene M. Zuckert, former Assistant Secretary of the Air Force, was sworn in as commissioner of the Atomic Energy Commission on February 25. This important post is one of a series of government appointments held by Mr. Zuckert in recent years. Since he has been concerned largely with management problems, both financial and organizational, it is assumed he will concentrate on such problems at the commission.

Mr. Zuckert was born November 9, 1911, in New York, N. Y., and attended Yale University. In 1937 he completed the combined law-business course at Harvard and Yale.

He has served as attorney for the U. S. Securities and Exchange Commission, member of the faculty of Harvard Graduate School of Business Administration, and special consultant to the Air Force on statistical control; in 1945, Mr. Zuckert became executive assistant to W. Stuart Symington, then administrator of the Surplus Property Administration. When Mr. Symington became Assistant Secretary of War for Air in 1946, Mr. Zuckert was appointed his special assistant. In 1947, when the Air Force was separated from the Army, he became Assistant Secretary of the Air Force under Mr. Symington.

Mr. Zuckert was appointed to fill the unexpired AEC term of Sumner T. Pike, which ends on June 30, 1954.

Joint Congressional Committee Names Strauss to Head Atomic Expansion Advisory Panel

Senator Brien McMahon has announced formation of the Atomic Plant Expansion Advisory Panel to the Joint Committee on Atomic Energy. Chairman of the panel will be Lewis L. Strauss, a former Atomic Energy Commission member and at present a consultant to the Joint Committee.

"The basic mission of the panel," Senator McMahon said, "is to advise and consult with the Joint Committee concerning various phases of the present and planned atomic construction program. Materiel priorities, labor relations, contract administration, organizational problems, the extent to which the plants are going forward with maximum speed and economy—these are some of the areas in which the panel will assist the chairman and members of the Joint Committee."

In addition to Mr. Strauss, the panel will consist of Ralph A. Bard, former Under Secretary of the Navy; James B. Carey of the CIO; Karl Compton, former chairman of the Research and Development Board; Roy T. Hurley, president of the Curtis Wright Corporation; Ralph E. McGill, editor of *The Atlanta Constitution;* and Boris B. Shiskin of the American Federation of Labor.

The Panel will require the preliminary assistance of qualified architect-engineering-construction specialists, whose task it will be to examine certain of the plants being built for the Atomic Energy Commission and to submit detailed technical reports for the use of panel members. Arrangements for this assistance are expected to be concluded shortly.

Additional Nuclear Sub and Plane Contracts Let

Speed-up on the building and development of nuclear-powered submarines and aircraft was indicated recently with the announcement of the awarding of three government contracts.

The Atomic Energy Commission gave the General Electric Company authorization for the immediate construction of G-E's land-based prototype of a nuclear reactor for submarines. The prototype reactor will be located in a special building to be constructed on a 4,000-acre site owned by the AEC in West Milton, N. Y., and will be used for final development work leading to construction of an intermediate energy reactor for submarine propulsion. The reactor will be housed in a steel sphere 225 feet in diameter similar to structures widely used in the chemical and petroleum industries.

The Electric Boat Company of Groton, Conn., is associated with G-E

as the submarine builder on this project and is serving in a similar capacity to Westinghouse Electric Corporation which is constructing a prototype reactor of different design at the National Reactor Testing Station in Idaho. An announcement last month indicated that Westinghouse would build the complete power plant for the nation's first atomic submarine, the *U. S. S. Nautilus*. A previous contract called for the company to design and engineer the project; it will now complete the job by constructing not only the reactor but also the propulsion equipment for the sub.

A contract for building a nuclear-powered plane was awarded to Boeing Aircraft Corporation last month by the Air Force. The company will work in conjunction with Pratt & Whitney Aircraft of East Hartford, Conn., which is developing a nuclear reactor to power the craft Boeing is to build. Similar cooperative development work on another plane was announced last year in connection with the award of contracts to G-E to develop an aircraft reactor and to Consolidated Vultee Aircraft Corporation to build the plane for it.

Sweden's Uranium Deposits Undergoing Survey

A survey of Sweden's uranium deposits has been started to try to lay the foundation for a future production of atomic energy. Whether Sweden is able to achieve a large-scale production is still unknown, although for some time now the Research Institute of the National Defense has been trying to find methods for extracting uranium from Swedish shale oil deposits.

Starting in 1946 when the Atomic Energy Committee was formed, industry, the government, five different university organizations, and the Research Institute for Experimental Physics in Stockholm, have carried on intensive research and experimental work in the field of atomic energy.

Sweden's first reactor, now being built near the capital after excavation into solid rock, is expected to start operation next year. Three to four tons of uranium will be needed for the reactor, which will be moderated by heavy water imported from Norway. At Upsala, a 200-Mev synchrocyclotron is nearing completion.

Inventory Shows Large Potential for Nuclear Research in American Colleges and Universities

Substantial resources for research in atomic and nuclear physics were recently reported by more than 100 American colleges and universities, according to an extensive inventory completed during 1951 by the Engineering College Research Council, a unit of the American Society for Engineering Education. Results of this inventory indicated the special interests and qualifications of 25,000 faculty members and 24,500 graduate students and junior staff in all physical and engineering sciences at 750 colleges and universities. The following table shows the number of schools which replied that at least one faculty member was experienced and qualified to undertake research in the fields of atomic and nuclear science:

	Number of Schools
PHYSICS	
High-energy particles and cosmic rays	70
Molecular and atomic physics	124
Neutron physics	51
Nuclear physics	155
Radioactivity and isotopes	115
CHEMISTRY	
Atomic and nuclear structures	49
Radiochemistry and tracer methods	115
ELECTRONICS	
Electron theory	106

Of the nearly 25,000 faculty members reported in all physical and engineering sciences, 20,000 were considered by their institutions to be qualified to perform research. Only 12,000 had research under way. An average of 52% of these teachers' time was spent on research, and on a national average 45% of this research time was devoted to studies sponsored by military agencies or their subcontractors.

Most college faculty members in atomic and nuclear studies are members of physics departments. In this departmental category, the survey showed a total of 2,628 faculty members in all colleges and universities. Of these, 2,272, or 86%, were considered qualified for research, and at least 1,546 had research projects under way. These qualified teachers spent an average of 63% of their time on research. At least 70% of this research time was devoted to defense projects, including studies sponsored by military agencies, the Atomic Energy Commission, or their industrial subcontractors.

Not all these physicists are in atomic and nuclear fields. But it is likely that a large part of the research time reported by physics departments is devoted to these areas.

As part of its survey of resources, ECRC also asked for listings of specialized research equipment that might be an important factor in the location of specific projects. The resulting list is in many respects inadequate, but it hints of a large complement of atomic and nuclear research equipment in American colleges and universities: 18 schools reported cyclotrons, 4 betatrons, and 6 synchrotrons; molecular-beam-research apparatus was listed by 11 schools, and 50 reported one or more cloud chambers for research use.

The survey project received reports from more than 700 colleges and universities and substantially all the research resources in the physical and engineering sciences at American educational institutions are included in the inventory. The full report of the project is entitled "University Research Potential." Copies are available, at $1 each, from the office of the Secretary of the Engineering College Research Council, 77 Massachusetts Ave., Cambridge 39, Mass.

AEC Announces Criteria for Land Acquisition

Describing the status of the new proposed expansion program of the Atomic Energy Commission, Marion W. Boyer, AEC General Manager, recently announced that the Commission is not at present in a position to state whether one or more major-facility sites may be required.

To provide public officials and the general public with information on the program at this stage and to prevent costly land speculation, the AEC let it be known that it is conducting preliminary studies of a number of areas in the United States to determine

those potentially suited for a major facility should it be required.

The criteria for evaluating an area include:

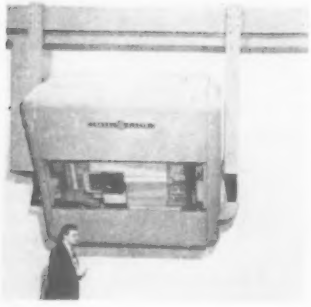
1. Technical operating requirements of the facility
2. Military considerations including vulnerability to attack
3. Public health and safety considerations involving the location and adequacy of the site to avoid possible hazards to surrounding area
4. Availability of land and its cost
5. Proximity to population centers so that workers can find housing and community facilities
6. Water supply that meets technical specifications
7. Soil and topography
8. Existing and potential water supply
9. Transportation, including railroads, highways, and airline service.

The areas being studied are large and some may contain as many as five or six potential sites, Mr. Boyer said. If and when a site is selected, the Commission will announce it publicly.

New York Academy to Aid in Work on Constants

Pointing out that many of the physical and chemical constants and properties of naturally radioactive substances urgently require revision, the New York Academy of Sciences has formed a committee to stimulate work in this field. The committee will make available certain radioactive substances on a gift or loan basis to qualified investigators interested in such studies, and the Academy will offer cash prizes for the best papers published as a result of the studies. The offer is restricted to American citizens residing in the United States.

For information on submitting a proposal for such research, address the New York Academy of Sciences, 2 East 63d Street, New York 21, N. Y.



GAIL ADAMS, University of California physicist, inspects 70-Mev synchrotron to be used for cancer therapy research. Recently installed at university medical school, the unit weighs 16 tons, was placed in room with concrete walls 30 inches thick. Patients will be viewed through liquid-filled window to protect operating personnel from X-radiation. A year will be spent on calibration and animal experimentation before machine is tried on humans. G-E's General Engineering Laboratories at Schenectady, N. Y., designed the unit and AEC paid for it

Isotopes-in-Industry Talks Planned for Ames

A Conference on the Use of Radioisotopes in Industry will be held from April 30 to May 1, 1952, at Iowa State College, Ames, Iowa. The second such conference to be held at Ames, it is open to all interested individuals and is sponsored by the school's Engineering Extension Service in cooperation with its Institute for Atomic Research.

The nature and handling of radioactivity, availability of isotopes, equipment, design of laboratories, and isotopic applications to industrial research, development, and control will be among the subjects covered.

Further details are available from Dr. Glenn Murphy, 101 T. and A. M. Lab., Iowa State College, Ames, Iowa.

Corporation Formed to Manage Canadian Reactors

Formation of a new crown corporation to manage Canada's atomic-energy work was announced recently by Canada's Prime Minister Louis St. Laurent. To be called Atomic Energy of Canada, Ltd., the corporation will have as its head, Dr. C. J. MacKenzie, president of the National Research Council and chairman of the Atomic Energy Control Board. It will take over the management of the nuclear reactors at Chalk River, Ont., as well as Canada's expanding nuclear research and plutonium production plant.

Agricultural Research Topic of Oak Ridge Symposium

The Fourth Annual Oak Ridge Summer Symposium, scheduled for August 25-29, 1952, will be devoted to discussions of "The Role of Atomic Energy in Agricultural Research." The symposium will be held under the auspices of the Oak Ridge Institute of Nuclear Studies and the Oak Ridge National Laboratory and will be sponsored by the University of Tennessee – Atomic Energy Commission Agricultural Research Program.

Additional information may be obtained from the University Relations Division of the Institute, P. O. Box 117, Oak Ridge, Tenn.

IN BRIEF

• The AEC estimates that 130,000 persons are presently employed in this nation's atomic energy program and that an additional 500,000 have worked for it at one time or another since 1943.

• *According to du Pont's latest annual report, the AEC's Savannah River plant, which the company is under contract to design, build, and operate for the Commission, is "probably the largest industrial project ever attempted." In many respects, the report continues, the work "is without precedent." Several hundred of du Pont's most valuable employees have been transferred from their regular work. The company undertook the project for a fee of $1.*

• A radioactivity laboratory has been set up at the University of Pennsylvania Museum in Philadelphia. In cooperation with the university's physics department, under Gaylord P. Harnwell, the museum is undertaking at least two projects that call for use of the carbon-14 technique, pioneered by Willard F. Libby of the University of Chicago and now commonly employed in dating ancient organic remnants. Arctic relics and Middle Eastern archaeological findings, including the remains of the Hotu man —probably the earliest human being yet found—will be examined.

• *Last month the AEC requested a super priority for scarce materials to prevent a possible six-month delay on the Savannah River plant under construction in South Carolina. The Joint Chiefs of Staff have the request under consideration to determine whether it would disrupt other programs of arms production.*

• British design studies of a prototype of a fast nuclear reactor that could be used to power ships and submarines have reached final stages, according to a recent statement by a spokesman

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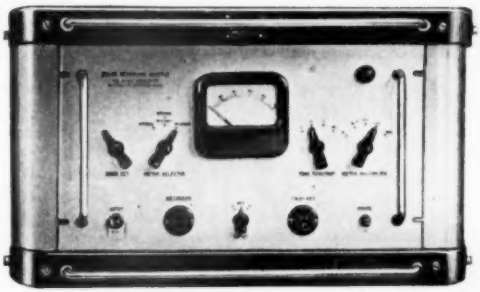

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for Great Britain's Ministry of Supply. Construction of the reactor will probably be started this year. It will take about a year to build and cost around $2-million.

• *An exhibit devoted to industrial uses of atomic energy will be featured at the Seventh National Chemical Exposition to be held September 9–13 at the Chicago Coliseum. In addition, the Chicago Section of the American Chemical Society, which sponsors the exposition, is planning a full day's program on the subject. Speakers will be announced later.*

• A Conference on the Use of Isotopes in Plant and Animal Research is going to be held at Kansas State College, Manhattan, Kansas, June 12–14, 1952. Further information can be obtained from R. I. Throckmorton, Kansas Agricultural Experiment Station, Manhattan, Kansas.

• *Westinghouse Electric Corporation has received $11,000,000 worth of orders from E. I. du Pont de Nemours & Co. in connection with construction of the AEC's Savannah River plant in South Carolina. Among the equipment to be supplied are three turbo-generators, eighteen large transformers, a considerable number of low-voltage circuit breakers and unit substations, together with station cubical switchgear and motors.*

• To fill the need of the AEC's reactor development program for more engineers, the Commission is considering sponsoring evening courses at industrial centers and short summer courses at educational institutions. These courses would be in addition to training available to experienced engineers at the Oak Ridge School of Reactor Technology (NU, Feb. '52, p. 10).

• *The Research Corporation has made two grants, worth $3,000, to the University of Idaho for nuclear research. Studies will be made to find the nuclear spin of osmium-187 and to compare values with the spin of rhenium-187, which is already known.*

• The University of Illinois is remodeling some of its engineering college facilities to accommodate a $20,000 AEC research project on the effect of radioactive materials in water supplies, sewage, and industrial waste.

• *Sylvania Electric Products, Inc., has been awarded a contract that calls for*

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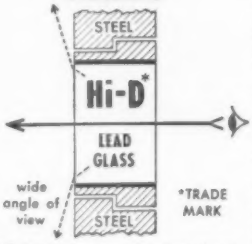

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expansion of the research and development work which Sylvania has been doing for the AEC since 1948. The work, in the field of nuclear reactor materials, will be carried out at the company's metallurgical laboratories at Bayside, N. Y. Five hundred people will be employed on the new project.

• Montana physicians are being introduced to atomic medicine through a 120-hour lecture-and-laboratory course on radioisotopes techniques given at the Medical Physics Laboratory of the Holter Research Foundation, Helena Foundation, Helena, Mont. Five Montana medical centers are in the process of setting up isotope units.

• *Spain recently set up an atomic energy commission to be responsible for all uses and applications of radioactive materials. The commission will carry out exploitation and will hold exclusive rights for obtaining, preparing, and processing of all such materials. Where prospecting is successful, the Spanish government will establish a reservation and bar private mining activities therein. Construction of a small nuclear reactor for medical and scientific interests is reported to be part of Spain's preliminary plans.*

• India is reported to have signed an agreement with the French government which calls for cooperation in the construction of a nuclear reactor for research and the production of radioisotopes. It will be India's first reactor and probably take about two years to build. It is expected that it will be located near the Travancore coast.

NUCLEAR NEWSMAKERS

John von Neumann, of the Institute for Advanced Studies at Princeton University, has been appointed by President Truman to membership on the AEC's General Advisory Committee. He has been named for the remainder of the term of **Cyril Smith,** director of the Institute for the Study of Metals at the University of Chicago. Dr. Smith recently gave up the committee work to devote all of his time to university work.

Harry A. Winne, vice president in charge of engineering policy of the General Electric Company, and **Hans A. Bethe,** professor of physics at Cornell University and former chief of the theoretical physics division of Los Alamos Scientific Laboratory, have

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been appointed to the Committee on Atomic Energy of the Research and Development Board. **Robert F. Bacher,** former member of the AEC, is the committee chairman.

Charles S. Simons, associate professor of physics at Louisiana State University, has joined the Oak Ridge Institute of Nuclear Studies as a senior scientist in the special training division.

Willard F. Libby of the University of Chicago has received the 1951 Research Corporation Award for his work on carbon-14 dating of archaeological remains. The award consisted of a plaque, a citation, and $2,500.

Russell S. Poor has taken a year's leave of absence as chairman of the university relations division of the Oak Ridge Institute of Nuclear Studies to join the National Science Foundation in Washington, D. C. Dr. Poor will head the research education section of NSF's division of scientific personnel and education.

George Gamow, nuclear scientist and professor of theoretical physics at The George Washington University, will go to Japan in May for a three-week lecture tour as one of four international figures invited to participate in the Japanese Peace Treaty celebrations.

Urner Liddel took up duties last month as chief of the physics and mathematics branch of the AEC's division of research. He formerly served as director of the division of physical sciences of the Office of Naval Research and administered the AEC-ONR joint program in nuclear physics research.

Horace S. Isbell, head of carbohydrate research at the National Bureau of Standards, recently received the Hillebrand Award of the American Chemical Society's Washington Section. He was cited for major contributions to the chemistry of sugar and for the synthesis of radioactive carbohydrates.

Raddie M. Wallace has been promoted to assistant manager of the Phillips Petroleum Company's atomic energy division at Idaho Falls, Idaho.

Walter J. Williams, deputy general manager of AEC, will assume, in addition to his present tasks, the duties of assistant general manager of manufacturing, a post held until recently by **Maj. Gen. Thomas F. Farrell,** who resigned. **James L. Keleham,** formerly assistant director of

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production, has been promoted to the place of assistant to Mr. Williams in both his functions.

Thomas H. Pigford has given up directorship of the Massachusetts Institute of Technology practice school at Oak Ridge to work with the reactor group at the Oak Ridge National Laboratory. He will return to MIT in June to take up appointment as assistant professor of nuclear engineering.

Don A. Miller has been named manager and **Henry L. Greene** assistant manager of operations for du Pont at the AEC's Savannah River plant.

Daniel J. Cavanaugh and **Arthur E. Heath,** radiochemists, have taken up positions with Nuclear Instrument & Chemical Corp. They are working on the company's new biosynthesized carbon-14-labeled sugars and algae program. **Robert D. Piper,** formerly with the Industrial Mobilization Branch, Army Corps of Engineers, has been named Nuclear's assistant sales manager.

Darleane Christian Hoffman, formerly of the Institute for Atomic Research at Iowa State College, is now doing research at the Oak Ridge National Laboratory.

MEETINGS

American Industrial Hygiene Association—Netherland Plaza Hotel, Cincinnati, Ohio, Apr. 22–24

Sixth Annual Symposium on Fundamental Cancer Research; also Cancer Pathology and Radiology Conference on Tumors and Other Diseases of Bone (sponsored by University of Texas and College of American Pathologists)—Shamrock Hotel, Houston, Texas, Apr. 25–26

National Academy of Sciences, Annual Meeting—Washington, D. C., Apr. 28–30

1952 Metal Powder Show, Metal Powder Association, 8th Annual Meeting—Drake Hotel, Chicago, Ill., Apr. 29–30

2d Conference on Use of Radioisotopes in Industry—Iowa State College, Ames, Iowa, Apr. 30–May 1

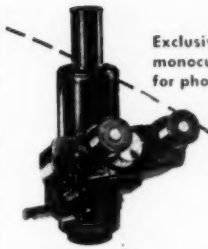
American Physical Society—Washington, D. C., May 1–3

The Electrochemical Society, 50th Anniversary Meeting, including Symposium on Rare Metals—Philadelphia, Pa., May 4–8

Scientific Apparatus Makers Association, Annual Meeting—Edgewater Beach Hotel, Chicago, Ill., May 6–9

Conference on Nuclear Energy (Atomic Energy and the Future)—Michigan State College, East Lansing, Mich., May 20–21

American Society of X-Ray Technicians, Annual Meeting—Morrison Hotel, Chicago, Ill., May 25–29



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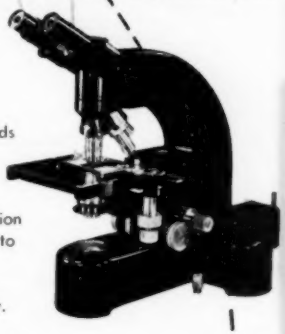

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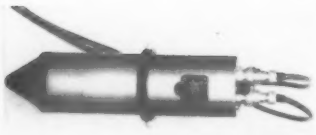

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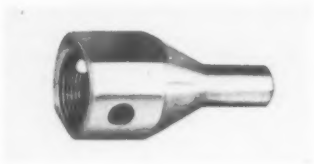

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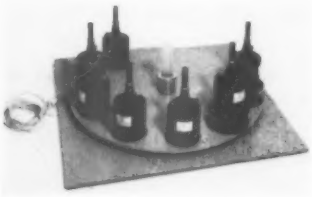

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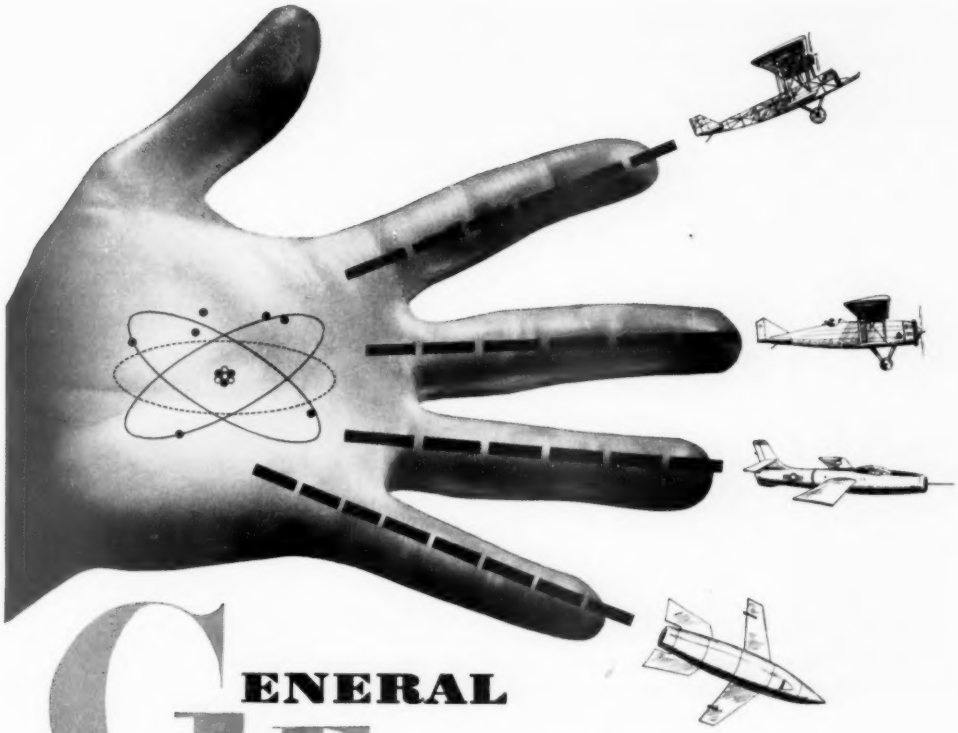

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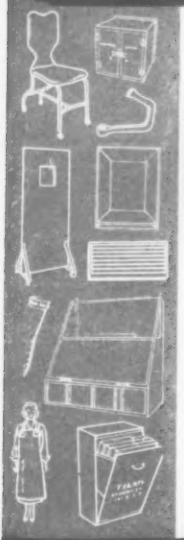

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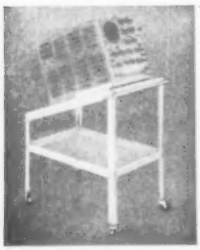

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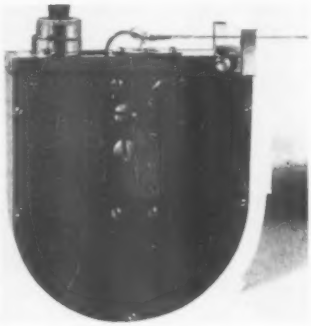

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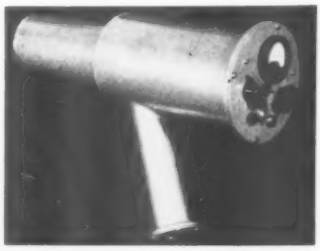

Scintiscope

R-C Scientific Instrument Co., 335 Culver Blvd., Playa del Rey, Calif. In the model CAX16P alpha scintiscope, pulses can be monitored audibly and are also accumulated by a rate-

metering circuit. There are five ranges with upper limits of 20, 200, 2,000, 20,000, and 200,000 cpm. Individual calibration adjustments are provided for each range. The detector is a ZnS(Ag) screen embedded in plastic, and mounted in a removable cap. A 5819 photomultiplier is used. A similar instrument, the model CAX17P is designed for detection of gamma and medium- and high-energy beta radiation. Ranges are the same as for the model CAX16P.

Tachometer

Metron Instrument Co., 432 Lincoln St., Denver 9, Colo. The rotary switch on this device can select one of ten overlapping and adjoining ranges, providing a 10-to-1 spread in speed. The indicating meter has three scales. Three models cover speeds from 36 to 100,000 rpm. Accuracy is said to be ¼%. No damage to the instrument can result from selection of the wrong range or overspeeding by 2 to 10 times full scale, it is claimed. Hand-engagement and fixed-installation heads are available.

Delay Lines

Technitrol Engineering Co., 2751 N. Fourth St., Philadelphia 33, Pa. Continuously wound lines are available with delays from 0.01 to 2.4 μsec, and impedances from 120 to 3,000 ohms. Maximum line-to-ground voltage is 50 volts. Rise time and attenuation depend on delay and impedance. The 0.75-μsec line with 1,000-ohm im-

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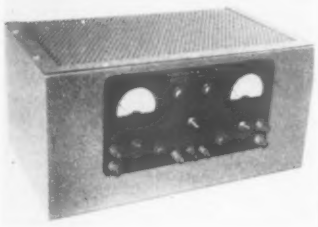
pedance has a rise time of 0.1 μsec and an attenuation of 2 db. The lines mount in standard 9⁄64-in. fuse clips.



Power Supply

Sorensen & Co., Inc., 375 Fairfield Ave., Stamford, Conn. The model 325BB "B-Nobatron" is a d-c power supply that provides an output of 0–325 volts at 0–125 ma, a bias voltage of 0–150 volts, and a filament supply of 6.3 volts, a-c, at 10 amperes. The output is floating so that either terminal may be grounded. It is claimed that regulation is good to ±0.5% between 20 and 325 volts, and that ripple is 10 mv. Models that provide power in other ranges are also available.

INDUSTRY NOTES

▶**Nuclear Instrument and Chemical Corp.,** 229 W. Erie St., Chicago 7, Ill., recently enlarged its plant area 20% by acquiring additional space in its present building. The additional space allowed the production and technical division, including the chemistry department, to expand facilities.

▶**The Austin Co.,** Special Devices Division, has new headquarters in the Port of New York Authority Building, 76 Ninth Ave., New York 11, N. Y. The move was made necessary by expanded activity in development, design, and production of computers, control systems, and other devices.

▶**Brown, Boveri and Co., Ltd.,** Baden, Switzerland, is expanding its operations to include particle accelerators. The company is ready to plan and build betatron installations from its own designs.

▶**Victoreen Instrument Co.,** 3800 Perkins Ave., Cleveland, Ohio, has acquired all stock of Pioneer Electronics

EXPERIMENTAL NUCLEONICS

By ERNST BLEULER and GEORGE JASON GOLDSMITH, both of Purdue Univ. Primarily a handbook for students in radioactive tracer technology, nuclear engineering, and nuclear physics, this book includes experimental procedures related to the measurement of radiations from radioactive sources, as well as information in regard to setting up and operating a tracerlab. Copiously illustrated with numerous tables, diagrams, and graphs, the book includes the Segre chart of the isotope.

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Corp., Salem, Mass. Cyrus W. Haller, Pioneer's president, has been appointed president of Victoreen. Additional manufacturing space has been acquired at New London, Ohio.

▶ **Nuclear Research Corp.,** 2563 Grays Ferry Ave., Philadelphia 46, Pa., has announced that Murray Makransky has been elected president to succeed H. Dickson Boenning. Mr. Makransky was treasurer and general sales manager. Norman Cherry was named vice-president in charge of production, and Charles E. Mandeville was named vice-president in charge of research.

LITERATURE AVAILABLE

Radiation detectors. Illustrated bulletin GEA-5735 describes detectors. *General Electric Co., Schenectady, N. Y.*

Gages. Catalog shows pressure gages. *F. W. Dwyer Mfg. Co., 317 S. Western Ave., Chicago 12, Ill.*

Seamless tubing. Catalog gives data on seamless metal tubing. *Uniform Tubes, Level Rd., Collegeville 2, Pa.*

Shunt. Bulletin gives specifications of electrometer shunt. *Keithley Instruments, 3868 Carnegie Ave., Cleveland 15, Ohio.*

Electron sterilization. Bulletin D describes commercial application of high-voltage-electron sterilization. *High Voltage Engineering Corp., 7 University Rd., Cambridge 38, Mass.*

Flexible shafts. Handbook gives data on flexible transmitting shafts. *S. S. White, Industrial Division, 10 E. 40th St., N. Y. 16, N. Y.*

Transformers. Bulletin describes saturable transformers. *Magnetic Amplifiers, Inc., 11-54 44th Drive, Long Island City 1, N. Y.*

Resistors. Catalog 51 lists line of resistors and controls. *Clarostat Mfg. Co., Inc., Dover, N. H.*

Connectors. Bulletins GB4-1951 and LS5-1951 give details on battery, laboratory, and switchboard connectors. *Cannon Electric Co., Box 75, Lincoln Heights Station, Los Angeles 31, Calif.*

Isotope instruments. Brochure discusses instrumentation for isotope utilization. *Nuclear Instrument and Chemical Corp., 223 W. Erie St., Chicago 10, Ill.*

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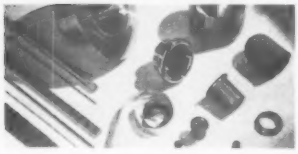

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Latrobe, Pennsylvania

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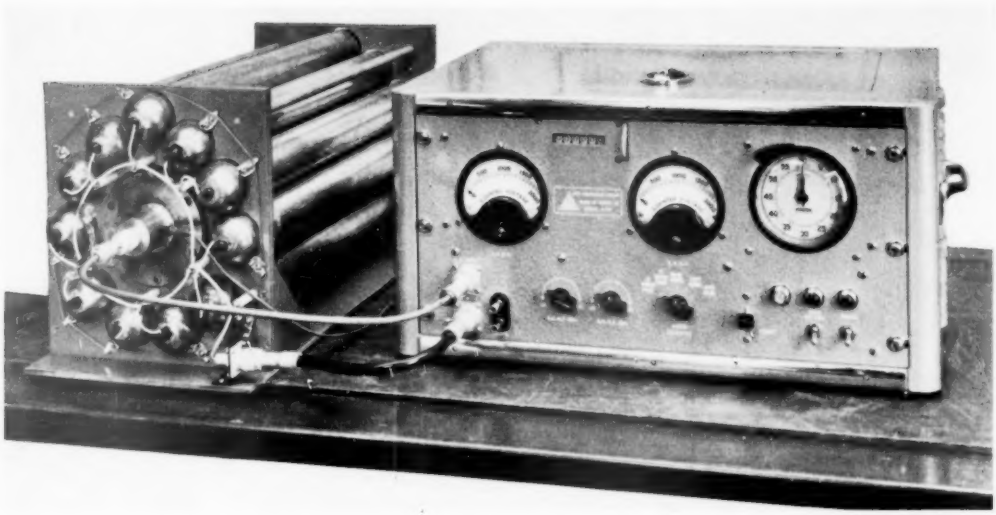

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Price, complete as shown	$1,795.00 each
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1. Latest Libby Screen Wall Counter with 8-inch active length. Internal cathode consists of grid wires for maximum detection sensitivity. Stop cock filling. Counter readily slides from anti-coincidence cage.
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3. Higinbotham scale of two circuit proved through years of use.
4. High voltage range 500 to 2000 volts.
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6. Voltmeters—finest obtainable.
7. Long term regulation—high voltage will change less than 10 volts at a 1900 voltage setting over a period of 14 hours.
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12. Power requirements: 200 watts at 105-125 volts, 60 cycle A.C.
13. Standard cabinet, 21½ in. x 15 in. x 10½ in., copper plated and finished in attractive smooth grey hammertone.
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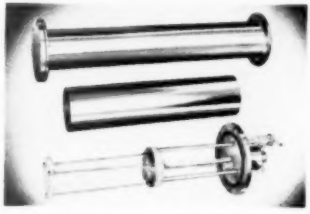

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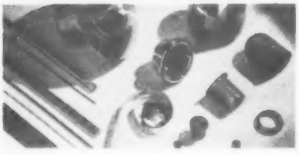

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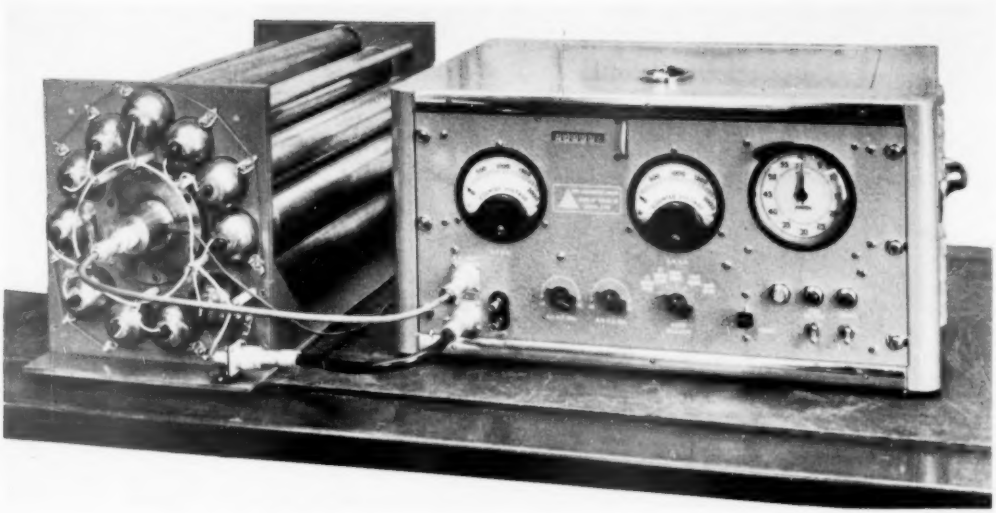

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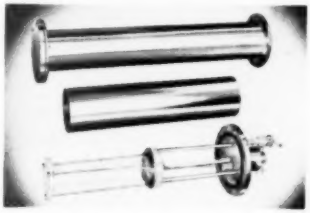

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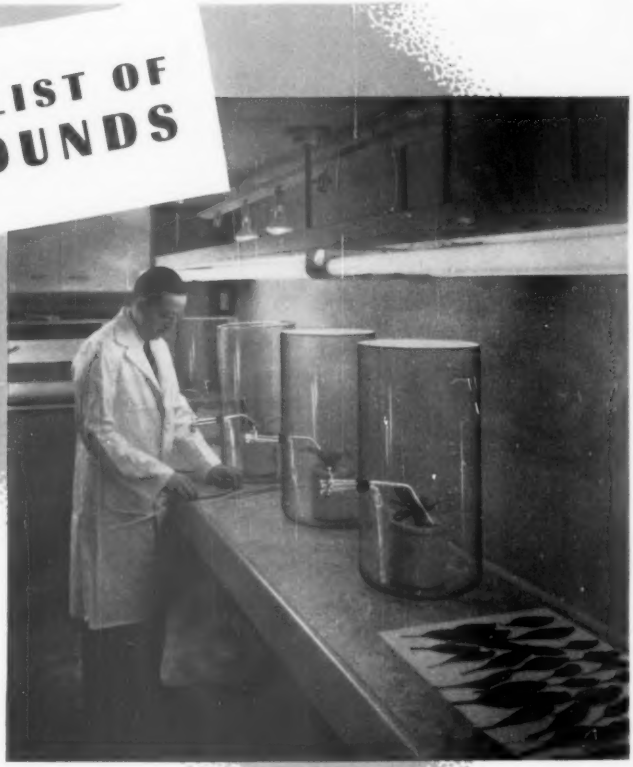

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